D. W. Keagler

Volume 23 SEPTEMBER, 1939 Number 9

BULLETIN
of the
American Association of Petroleum Geologists

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BULLETIN
of the
AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
OFFICE OF PUBLICATION, 608 WRIGHT BUILDING, TULSA, OKLAHOMA

THE BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS is published by the Association on the 15th of each month. Editorial and publication office, 608 Wright Building, Tulsa, Oklahoma. Post Office Box 979. Cable address, AAPGEOL.

THE SUBSCRIPTION PRICE to non-members of the Association is $15.00 per year (separate numbers, $1.50) prepaid to addresses in the United States. For addresses outside the United States, an additional charge of $0.40 is made on each subscription to cover extra wrapping and handling.

British agent: Thomas Murby & Co., 1 Fleet Lane, Ludgate Circus, London, E. C. 4.

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BOX 979
TULSA, OKLAHOMA

Entered as second-class matter at the Post Office at Tulsa, Oklahoma, and at the Post Office at Menasha, Wisconsin, under the Act of March 3, 1879. Acceptance for mailing at special rate of postage provided for in section 1103, Act of October 3, 1917, authorized March 9, 1923.

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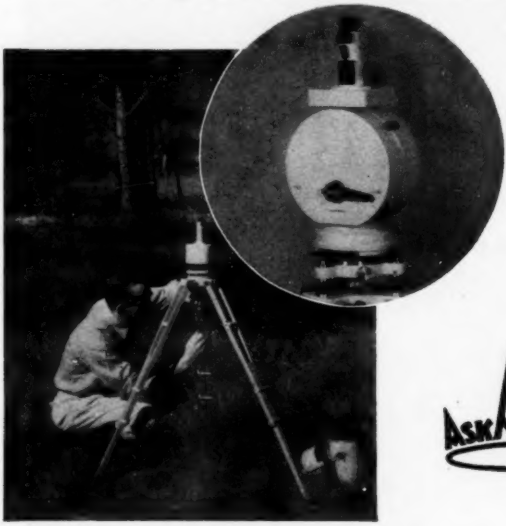

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Volume 23 Number 9

BULLETIN

of the

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

SEPTEMBER, 1939

ELECTRICAL WELL LOGGING[1]

HOUSTON GEOLOGICAL SOCIETY STUDY GROUP
Houston, Texas

Study Group members.—This report is a summary of the work done over a period of several months, by the Houston Geological Society study group interested in electrical well logging. Members of the group were: J. L. Mathieu, leader, Ralph Cantrell, Paul K. Goodrich, John Graham, Ford Hubbard, M. M. Kornfeld, Leigh Masterson, Frank C. Roper, G. J. Smith, K. K. Spooner, John D. Todd, and Joseph Zaba.

Acknowledgments.—Various members of the group have contributed different parts of the paper, particularly Zaba on the self-potential curve, Smith on the resistivity curve, Spooner and Masterson on sands, Graham and Cantrell on reactions in salt.

The group is indebted to J. L. Mathieu who gave freely of his time. However, the ideas and conclusions expressed in the report represent the personal work and opinion of the members contributing each section of the paper. Mathieu disclaims all responsibility for the statements and conclusions which appear in the report.

INTRODUCTION

Electrical well logging has been used in the field commercially for almost a decade, and it is now practically as indispensable to the oil industry as the bit itself.

In this paper a discussion of technical matters and routine results has been avoided. Since almost everyone is already familiar with the general cases and their interpretation, time has been devoted particularly to study of certain applications and interpretations of the electrical curves showing peculiar characteristics due to abnormal conditions.

ELECTRICAL CURVES

Several arrangements for electrical logging are in existence at the present time. They vary essentially in the number of electrodes, the number of conductors, type of circuits used, *et cetera*. From a practical point of view their results are comparable. To avoid any controversial comparisons only one arrangement, the multi-electrode type, is discussed.

[1] Manuscript received, June 30, 1939.

Two types of electrical diagrams are obtained.

A. A natural or self-potential diagram which is the result of an electrical potential generated naturally in a drill hole without sending any additional electrical energy into the ground or hole by means of a battery or generator.

B. One or several resistivity diagrams which are the result of measurements of the difference of potential impressed on two electrodes by an outside electrical current sent into the ground.

PART I

SELF-POTENTIAL DIAGRAM OF ELECTRICAL LOG

The so-called "self-potential diagram" of an electrical log expresses phenomena which are ascribed primarily to electro-filtration. In other words, it is believed that the diagram is a measure of an electromotive force occurring when an electrolyte—in the case of wells the water of the mud in the drill hole—is caused to flow through a pervious solid dielectric—in the case of wells a porous stratum.

Field experience and laboratory experiments showed that electro-filtration is not the only cause of the spontaneous electrical phenomena registered by the self-potential diagram. The electro-chemical action, or electro-osmosis, also plays a part which should not be overlooked.

Since these two phenomena can occur in a well only at points where the well traverses a more or less porous stratum, the diagram is frequently referred to as a "porosity diagram." The name is misleading since the electromotive forces caused by electro-filtration and electro-osmosis are functions of several factors and, although indicating porosity, do not necessarily represent the absolute porosity.

ELECTRO-FILTRATION

The electromotive forces caused by electro-filtration are directly proportional to the pressure and electrical resistivity of the liquid and are inversely proportional to its viscosity. For example, the amplitude of a self-potential diagram can be readily changed by changing the level of the fluid in the drill hole. The electromotive force is independent of the thickness of the porous stratum and of the radii and number of pores.

The direction of the current is the same as the direction of filtration. Theoretically, three possible cases can, therefore, occur (Fig. 1).

1. If the formation pressure is higher than the hydrostatic head, the formation discharges fluid into the hole, and the diagram will have a positive characteristic.

2. If the formation pressure equals the hydrostatic head, there will be no current present due to electro-filtration, and the value on the diagram will be zero even in front of a porous formation.

3. In most cases the hydrostatic head of the fluid in the hole is higher than the formation pressure, the fluid and the current enter the formation and the diagram will show in front of the layer a negative value.

Cases 1 and 2 will rarely if ever be found in practice.

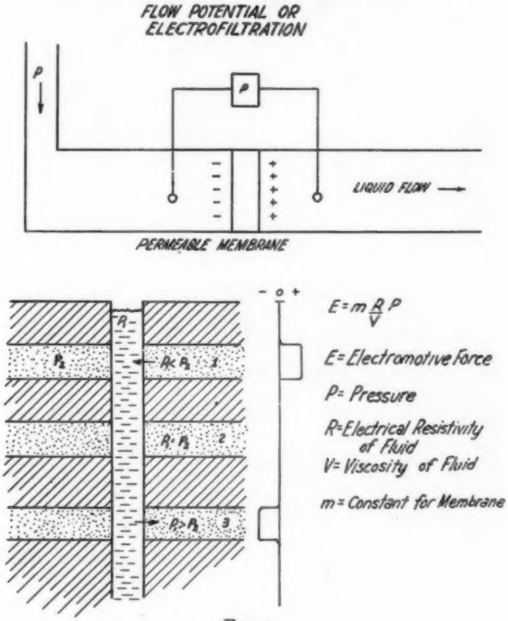


FIG. 1

ELECTRO-OSMOSIS

Another cause of the spontaneous electrical phenomena in front of a porous layer is electro-osmosis. When two electrolytes come in contact, an electromotive force is generated. In the case of drill holes, the electrolytes are drilling mud and the salt water of the formation. Below certain depth level, all formational waters contain salts in large amounts, even those connected with oil sand, the latter in the form of connate water. Field experiments have shown that the value of the self-potential can be changed, to some extent, by changing the salinity of the drilling mud.

As in the case of electro-filtration, electro-osmosis, when considered alone, may be illustrated by three arbitrary cases (Fig. 2).

1. If the concentration of salts, or the salinity of the water, in the sand is higher than that of the drilling mud, the current enters the formation, and a negative anomaly with respect to shale is observed opposite the porous zone.

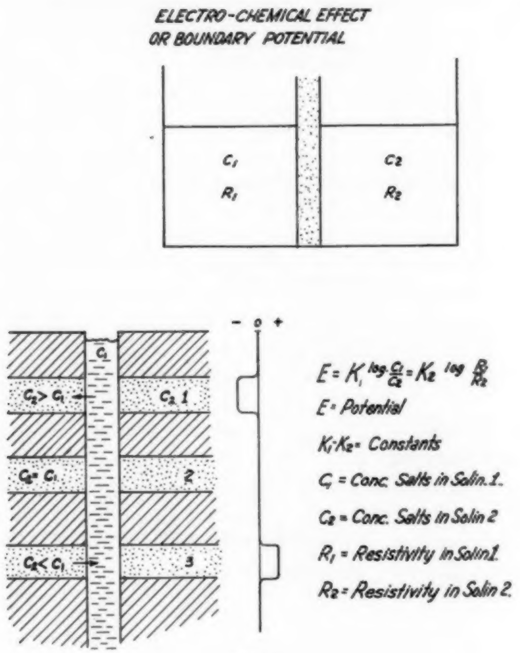


FIG. 2

2. If the salinity of the mud is equal to that of the water in the sand, there is no potential generated due to electro-osmosis, and hence no potential difference is observed between sand and shale.

3. If the mud is saltier than the formational water, the current enters the hole, and a positive anomaly may be observed opposite a porous zone.

Case 1 corresponds to normal conditions in bore holes traversing the productive zone. The drilling mud, which has been made with fresh water from the surface, will be less saline than the water in marine formations.

RESULTING CURVE

From the foregoing, it is obvious that the self-potential diagram as shown during an electrical survey of a well is a resultant of the phenomena of electro-filtration and electro-osmosis, and that theoretically there are several possible combinations of the cases previously

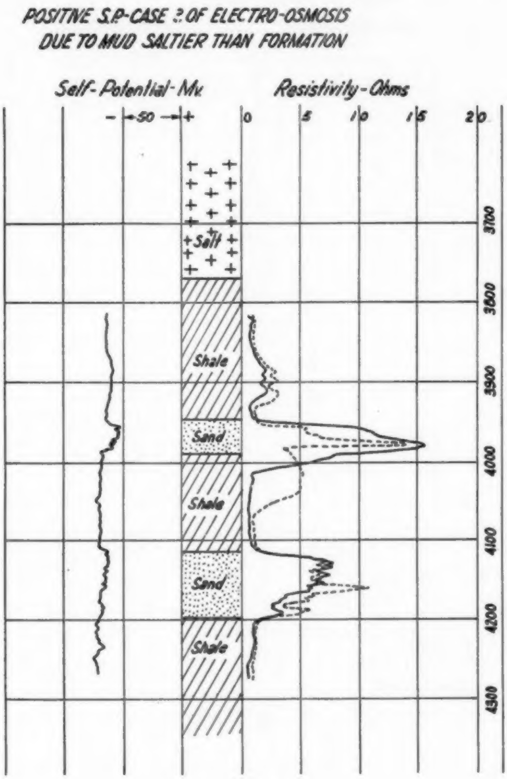


FIG. 3

discussed. The resultant is an algebraic sum of the two components, which suggests in special instances the necessity of a careful investigation of the factors involved if correct interpretation of the diagram is to be had. For instance, it is theoretically possible that the diagram will show no anomaly in front of a porous formation if the salinity of the mud equals the salinity of the water in the formation and if formational pressure equals hydrostatic head. In practice, however, such a combination is rare, and some indication is usually registered.

REVERSAL OF SELF-POTENTIAL SIGN

On deep formations, the self-potential recorded is ordinarily negative, being the algebraic sum of Case 3 of electro-filtration and Case

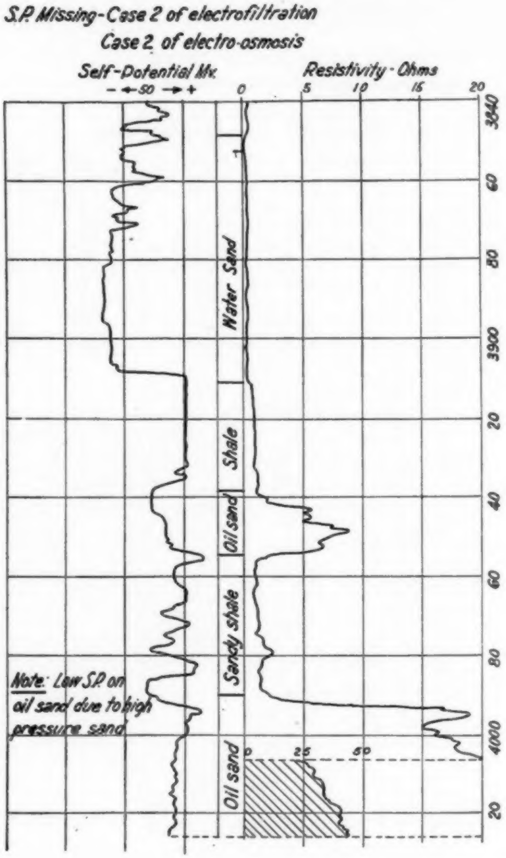


FIG. 4

1 of electro-osmosis. Abnormal conditions, however, are sometimes encountered, as indicated in the three following examples.

a. Drilling through a salt section (overhang or salt layer) will give a salty mud, which is sometimes saltier than the formation water. In this case, the self-potential effect may become positive (Fig. 3).

b. It may happen that a well ready to blow out from a deep sand will give little or no self-potential effect. This is due to fluid from the sand which is entering the hole, reducing the electro-filtration effect (Fig. 4).

S.P. POSITIVE – CASE 1 OF ELECTROFILTRATION

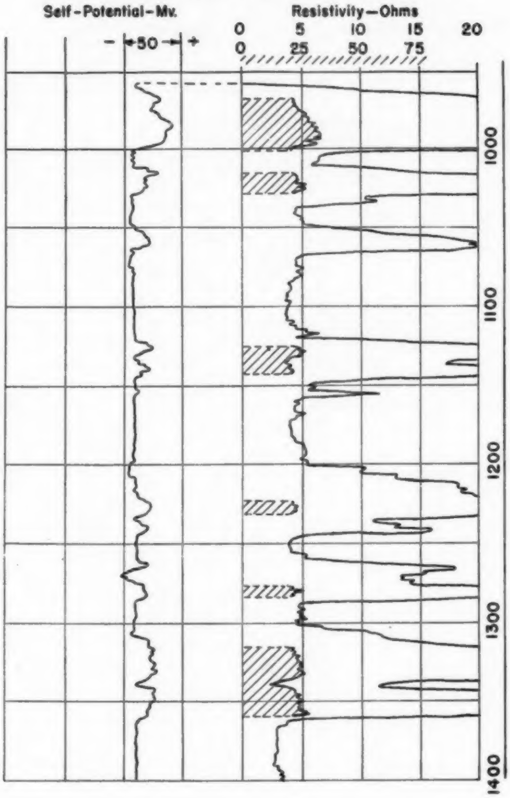


Fig. 5

c. A case similar to b may be encountered at shallow depths when there is an artesian sand flowing water into the well (Fig. 5).

In rare instances, it is possible to see a complete reversal of the self-potential sign in a single well, a change from a negative value on deep sands to a positive one on the shallow sands (Fig. 6).

RANGE OF VALUES

The self-potential generated in a drill hole can reach very high values. A value of 150 millivolts is common, and the maximum values registered today are in the order of 250–300 millivolts.

REVERSAL OF S.P. FROM NEGATIVE TO POSITIVE

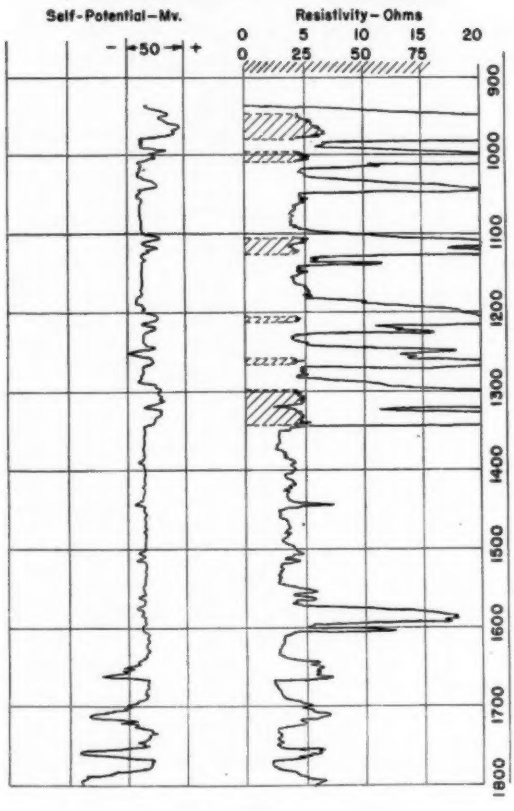


FIG. 6

The self-potential will usually increase with depth for two reasons: (1) increase in differential pressure, and (2) increase in salinity of the formation water with the depth. The increase of salinity of the formation with depth is the result of both an increase in pressure and in temperature.

BASE LINE

It was observed long ago that with decreasing depth, the self-potential base line would slightly drift toward the negative.

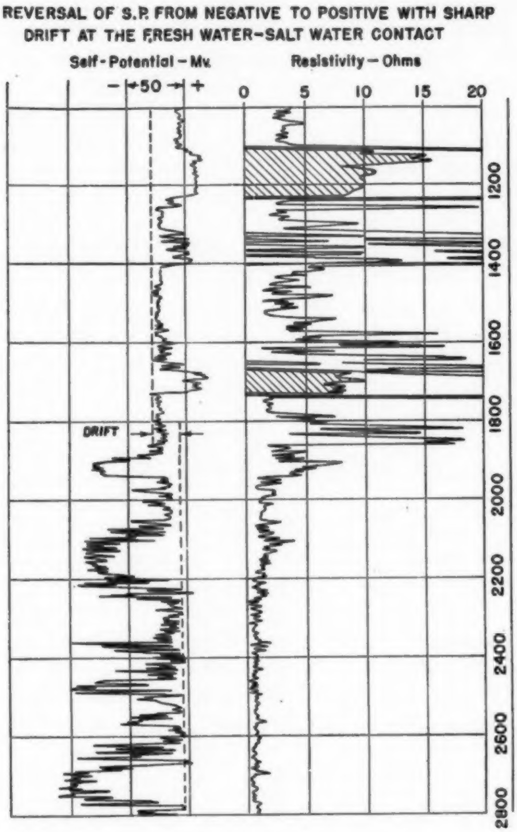


FIG. 7

In fact, it is not unusual to observe a change in the base line of the self-potential in a particular field, and this change can be used as a correlating point (Fig. 7). Self-potential values must be measured, using as a base line the shale situated next to the porous section giving a self-potential peak.

MEASURING SELF-POTENTIAL

The self-potential is measured by running an electrode on an insulated conductor into the well (Fig. 8). The upper end of the conductor is connected to a grounded electrode, the potential of which must be constant and is arbitrarily assumed to be zero. For

SELF-POTENTIAL MEASUREMENT

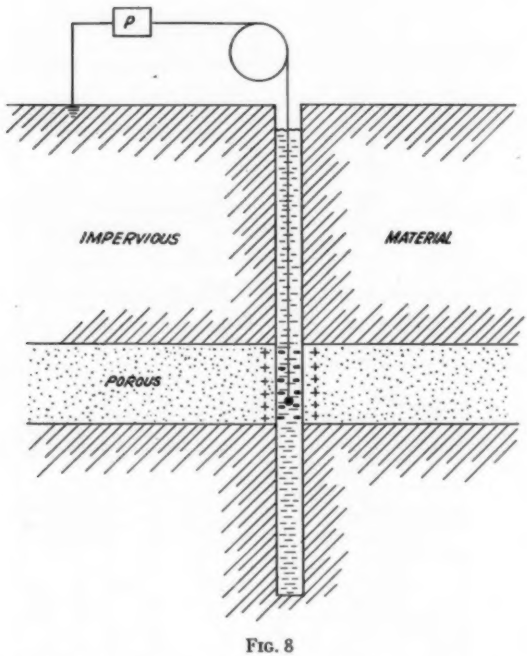


FIG. 8

each position of the electrode in the well, the potentiometer will give the value of the difference of potential between the potential at this particular point and the potential of the ground electrode.

PART II

RESISTIVITY DIAGRAM OF ELECTRICAL LOG

In the lithosphere, there is nowhere a condition of uniform electrical conductivity, or, conversely, resistivity. Rocks differ greatly in

respect to this property, depending primarily not on the varying minerals of the rock, but on the physical characteristics of the rock and on the water which the rock contains. This may be (1) adsorbed or connate water which is incapable of circulation and such as is present in the very minute interstitial spaces of shales and clays, or (2) absorbed water such as is found as both fresh and salt water in permeable formations like sands and porous limestones, and which is free to circulate. Some dense rocks, such as granite, quartzite, gneiss, marble, gypsum, rock salt, coal, and lignite, have so little interstitial space, and therefore so little connate moisture, that they are very poor conductors of electricity and hence have a high resistivity. Thus the electrical resistivity of a permeable rock body or formation is primarily dependent on its content of water and particularly on the nature and amount of soluble salts dissolved in this water.

In addition to various waters, either fresh and electrically resistant or saline and electrically conductive, the content of the interstitial spaces of rocks may be filled with oil or gas. Inasmuch as these hydrocarbons are not electrolytes and therefore not conductive, any formation containing them to the exclusion of saline waters (other than connate) will be characterized by a relatively high resistance.

INFLUENCE OF TEMPERATURE

The influence of temperature needs also to be mentioned briefly. An increase of temperature decreases the resistivity of the rocks for two reasons: (1) the resistivity of an electrolyte of a given concentration decreases as the temperature increases, and (2) the percentage of dissolved salts increases with the temperature. In general, the specific resistance of an electrolyte decreases by $\frac{1}{2}$ for an increase of 90°F. This fact has an appreciable influence on the resistivity measurements made in drill holes, since temperature differences of 90°F. between the surface and the bottom of a hole may be encountered. For this reason, the electrical resistivity will have a tendency to decrease with increasing depths.

Granted that the electrical resistivity of rocks varies and that the relative resistivity may be accurately measured, the next step is to apply the measurement of this phenomenon practically to the study of the subsurface formations penetrated by drill holes. In general, the resultant resistivity curves may be classified in four groups.

CLASSIFICATION OF RESULTANT RESISTIVITY CURVES

1. High resistivity in permeable formations, which may be caused by the following content of the formation (Fig. 9)
   a. Fresh water, ordinarily found at relatively shallow depths

   b. Sulphur water, ordinarily rather rare and localized in its occurrence. It may occur at depths considerably below the fresh-water table
   c. Oil and gas

2. Low resistivity in permeable formations, which is caused by the presence of electrically conductive, saline waters in the pore spaces of the rock

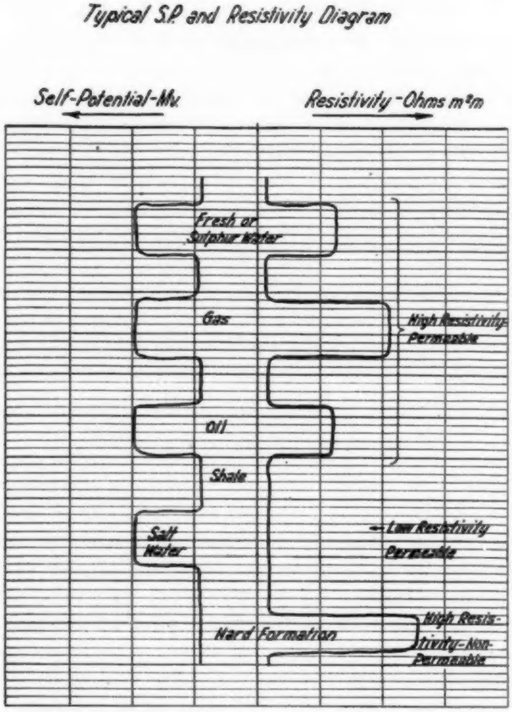


FIG. 9

3. High resistivity in non-permeable formations, which is characteristic of the following
   a. limestone
   b. anhydrite
   c. coal
   d. lignite
   e. rock salt, *et cetera*

   In this group, high resistance is due to density and compactness of the rocks, and small interstitial space, making impossible the presence of an appreciable amount of connate moisture which might serve as a conductor

4. Low resistivity in non-permeable formations, which is typified by shales and clays which contain sufficient amounts of adsorbed saline water in their minute pore spaces to serve as an electrical conductor

FACTORS AFFECTING RESISTIVITY DIAGRAM

These four examples form simple groupings of the various common formations ordinarily encountered in drill holes—formations whose resistivity characteristics may be generalized. However, there are complications and variables which render the evaluation of resistivity

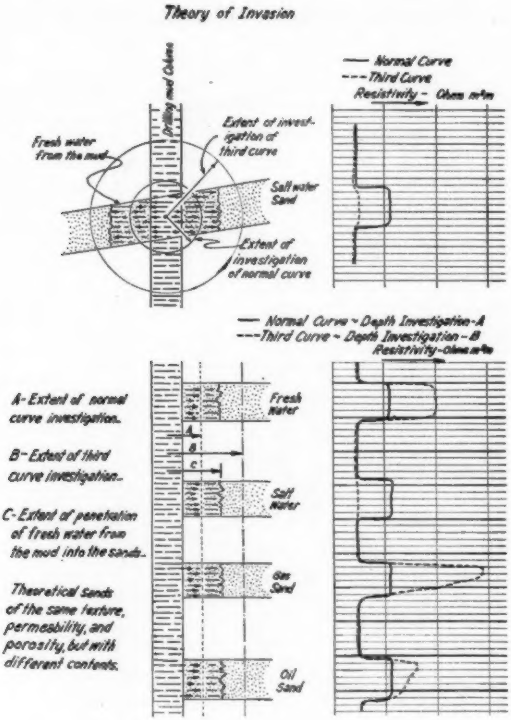


FIG. 10

measurements more complex than would at first appear to be the case. The most influential ones are: invasion, colloidal material in the sand, and salinity of the drilling mud.

1. *Invasion* (Figs. 10 and 11).—The normal resistivity curve measures the resistivity of the formation only a short distance, back and away from the face of the drill hole. Because of differential pressure, there is commonly a slow migration of the fresh water in the drilling mud back through the face of the hole and into the more

permeable formations. The more permeable the formation, the greater will be the extent of migration into, or invasion of, the formation by

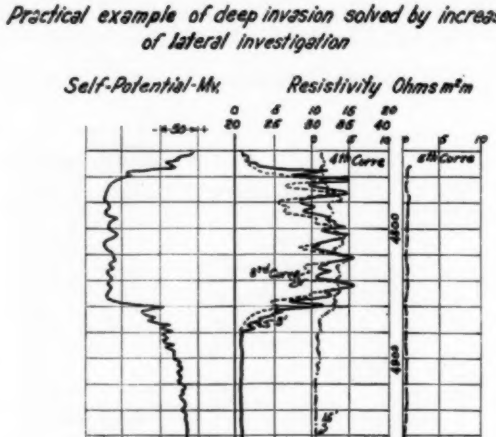
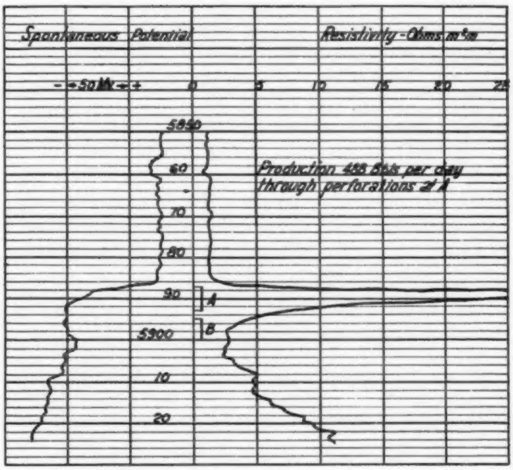


FIG. 11

water from the drilling mud. If this water is fresh and invades a salt-water sand, let us say a lateral distance of 5 or 6 feet, a measurement of resistivity will indicate that the content of the formation is highly

resistant. On the other hand, if the water of the drilling fluid is salty and invades an oil sand, it will reduce considerably the value measured on a resistivity log. Thus we see that, in case of invasion, one resistivity measurement may not permit the complete determination of the nature of the fluid initially present in the formation. It then becomes necessary to measure the formation resistivity a sufficient distance away from the drill hole to be beyond the influence of the

COLLOIDS ~ CONNATE WATER



	Porosity %	Perm. ⊥ md.	Perm = md	Silt %	Colloids %	Salinity P/mil	Oil Sat. %
A	28.5	6630	4780	0.36	1.64	600	26.7
B	25.7	262	210	2.47	14.71	3000	12.5

FIG. 12

invading water. This is accomplished by a lengthening of the electrode spacing in the hole, with the result that the depth of lateral investigation is considerably increased.

Thus, it becomes evident that not only one or two, but several, resistivity curves may be necessary to solve many of the problems. Because of the foregoing, more than one resistivity curve is usually recorded in the Gulf Coast territory. These resistivity curves have very definite characteristics, which are beyond the present study.

2. *Colloids* (Fig. 12).—Another complication in the interpretation of resistivity curves presents itself in the case of permeable formations which contain relatively large amounts of colloidal material. This colloidal material (bentonite, fine clays, *et cetera*), because of its adsorbed saline water which increases the percentage of connate water, acts as a conductor of electricity. When this occurs in an oil or gas sand, the conductive colloids permit the current to pass through the formation, with the result that lower resistivity is registered. This condition is accompanied always by a decrease in the permeability of the formation, though not necessarily in the value of the self-potential diagram.

3. *Salinity of drilling fluid.*—The resistivity of the fluid filling the hole, of course, plays some part in the measured relative resistivity of the formation. If this fluid is very salty, the mud column becomes very conductive and therefore absorbs a certain part of the current, thus reducing the difference of potential between the measuring electrodes. This results in a lesser differentiation between conductive and resistive formations.

The influence of salty mud can ordinarily be minimized by replacing the salt water with fresh water. When drilling through an overhang or a salt layer, the mud becomes a brine and, at that time, it is often useful when readings are desired below the salt to displace the salt water at the bottom with fresh water with as little circulation as possible. On the other hand, if the fluid is a non-conductor, oil for example, the electrodes become submerged in an insulating fluid which prevents either sending to or receiving a current from the formations. This condition is usually overcome by obtaining a direct contact between the electrodes and formations by means of brush electrodes.

In passing, it is of interest to note the action of the resistivity curves as they reflect a depleted oil sand. Cores taken in such a sand normally show oil still left in the sand. However, the salt water which ordinarily follows into the pore spaces as the oil is withdrawn acts as a conductive agent, with the result that a low resistivity is recorded. Thus, "bleeding core" formations are easily recognized by a low resistivity on an electrical diagram.

Summarizing the resistivity study briefly, the following points may be noted.

1. Rocks and formations vary greatly in their electrical resistivity.

2. The resistivity is dependent not primarily on the mineral characteristics but on the water content of the rock and its physical characteristics.

3. Saline waters offer good conductivity, or conversely, low resistivity. Fresh waters, sulphur waters, oil, and gas are poor conductors; hence, they are indicated by high resistivities.

4. Formations too dense to contain either absorbed or adsorbed water are always highly resistant.

5. Experience in the use of electrical logging permits the general grouping of formations and formational contents into definite classes, and an accurate determination of their characteristics.

MEASURING RESISTIVITY

Briefly, the technique of measuring resistivity as usually applied to rocks encountered in drill holes is as follows.

Several insulated cables, encased together, are lowered into the hole. On the end of each cable is attached an electrode, one of them being used to pass current into the ground and the other to measure the difference of potential caused between two or more points by the passage of current through the ground. To one pole of the source of current is attached the cable carrying the lowest or deepest electrode, the other pole being grounded at the surface, customarily in the mud pit. In order to measure the difference of potential between the other electrodes, the other cables are connected to one or several suitable instruments at the surface. The recording of the resistivity is made automatically on a sensitized film.

PART III

APPLICATION AND CORRELATION

The applications of electrical logging are already numerous and have become increasingly valuable from year to year chiefly for two reasons: (a) improvement resulting in additional information, and (b) greater number of logs and therefore better comparative facilities.

One of the most widely accepted uses of electrical logging diagrams is for subsurface correlation. Geologists in particular are quite familiar with this application. Since the subject of subsurface studies by electrical diagrams is covered elsewhere, the discussion here is limited to generalities and to the "mechanics" of correlation. Three types of correlation exist: (A) short-distance correlation, or detailed study of oil fields; (B) long-distance correlation, or regional study; and (C) near-surface correlation, or structural correlation.

A. SHORT-DISTANCE CORRELATION OR DETAILED STUDY OF OIL FIELDS

Since each type of formation has its own relative value of self-potential and resistivity and every particular zone its pattern, the

resulting log affords an easy and accurate means of distinguishing between the different formations. Close study of electrical diagrams of the same field will usually reveal: (a) faulting with an indication of the throw and cut-out section, and (b) lensing.

However, in attempting to correlate logs in a field, one should keep in mind the following.

1. Ordinarily, in the Gulf Coast the self-potential log is essential for correlation, but very important information is commonly obtained from the resistivity logs, particularly in shale sections where minute details are of great help in these correlations.

2. A fault is indicated by a missing section, and the difficulty of recognizing them ordinarily results from trying to correlate sand by sand, or formation by formation, instead of by large groups.

3. It is always a mistake to emphasize a doubtful correlation by the use of different colors. The fact that the same color is sometimes applied to different sands which have been incorrectly correlated makes it practically impossible to separate them again. In other words, coloring does not help to make a correlation; it emphasizes a correct correlation but conceals the error of an incorrect correlation. However, the use of the same color, such as yellow, for all sands, is desirable to make the peaks stand out prominently.

4. Very good results are commonly obtained by first correlating the logs by the use of transparent prints, using large groups for the purpose of establishing the necessary number of markers, five to ten for instance, and placing them side by side on a table so as to view them at a distance. Wall correlations in particular are very good.

B. LONG-DISTANCE CORRELATION OR REGIONAL STUDY

The long-distance correlation is made from field to field or from wildcat to wildcat, both along the strike and perpendicular to it, for regional study and also to study the dip, occurrence of structures, gradation of one formation into another, gradual variation in salinity of the formation, *et cetera*.

The result is obtained only by the use of large groups and of very definite and easily recognized markers. It is often aided by additional lithological or paleontological markers.

C. NEAR-SURFACE CORRELATION OR STRUCTURAL EXPLORATION

Expensive, tedious, and often inaccurate subsurface correlations have been attempted in the past by means of core drilling. The results have varied in quality and cost according to the territory where the method was used. It has been most unsatisfactory in the Gulf Coast

because of the lack of shallow paleontological or lithological markers.

The poor results obtained in the Gulf Coast by core drilling have strengthened the theory that deep structures are not reflected on shallow young beds. However, recent advances in geological studies

NEAR SURFACE LOCATION OF A FAULT
BY SHALLOW HOLES

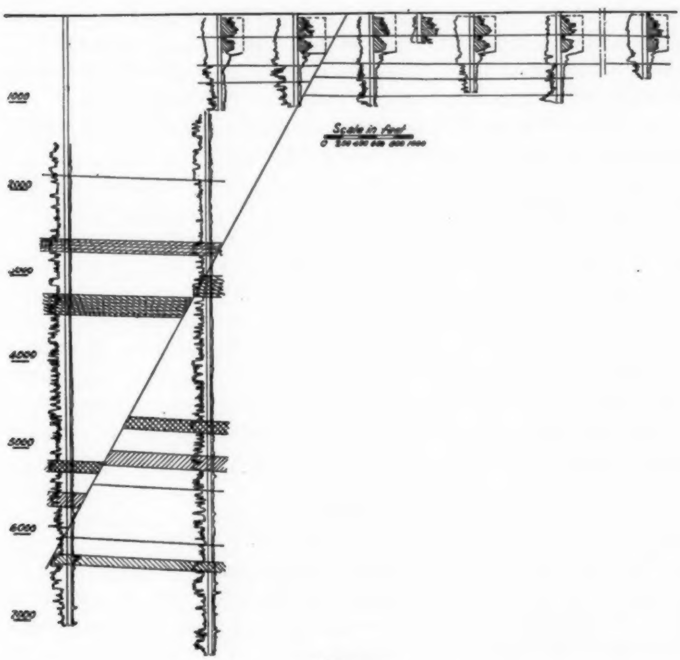


FIG. 13

connected with salt domes have revealed such an unexpected prevalence of faulting that the question immediately arose whether faults showing several hundred feet of throw in the production zone should be expected to disappear entirely at shallow depths.

In pursuing this inquiry, the use of electrical logs has revived, so to speak, the practice of working out shallow subsurface correlations.

In this work, shallow, small-diameter holes (3–4 inches in diameter and about 1,000 or more feet deep) are drilled at full speed without coring or sampling, solely for the benefit of the correlations obtained from the electrical diagrams. The results here summarized have been wholly satisfactory.

1. Correlations are always obtainable regardless of the age of the formation. This has been demonstrated in many different territories, such as the salt-dome area of the Gulf Coast, the Conroe trend, Southwest Texas, West Texas, Kansas, and Oklahoma with equal success.

2. Most of the faults shown at great depths are present in the upper beds. As a rough generalization, one-tenth of the throw existing at 7,000 feet, or 8,000 feet, is present at 1,000 feet. Thus, grabens are located, upthrown or downthrown blocks are outlined, and interrelations of various seismograph highs are established.

3. The dome itself is ordinarily reflected either by an arch or depression in the near subsurface formations.

It is understood, of course, that deep structures do not of necessity correspond with shallow ones. However, the correspondence is so common, especially in the Gulf Coast, that the shallow correlation process has proved to be a definite step toward sounder structural studies.

Figure 13 illustrates how a fault having 500 feet of throw at 6,000 feet and 250 feet of throw at 3,000 feet makes its appearance near the surface where at 700 feet it still retains a 65-foot throw. This fault is located in South Louisiana where structures are exceptionally deep and are overlain by a great thickness of comparatively young formations, yet it shows clearly on the shallow log.

PART IV

INTERPRETATION OF FORMATION CONTENT

The interpretation of the formation content is that aspect of the subject with which the petroleum engineer is particularly concerned. To make a complete study of it would mean to analyze all the possible interpretations of the electrical diagrams, and this constitutes a field of study within itself. The discussion, therefore, is limited to a brief generalization of the typical reaction of fluids in the various formations ordinarily encountered in a well.

1. *Sands.*—In considering sands, it is well to mention again that the conductivity of a porous formation is in direct relation to the amount of salt water it may contain. Since the water content is a function of the lithologic character, it is, therefore, necessary to

distinguish between clean sand, dirty sand, and cemented sand.

A. *Clean sand.*—Clean sand can be defined as being homogeneous and composed of sand grains of various size and relatively void of impurities such as bentonite, volcanic ash, calcareous material, *et cetera*.

(1). *Clean sand—resistive.*—If the clean sand contains only a resistive fluid, such as gas, oil, fresh water, or sulphur water, it should be highly resistive. However, in practice salt water in connate form is usually present which will lower the resistivity to some extent. Also, since the finer-grained sands ordinarily contain more connate water, they generally are less resistive than coarser sands.

In this connection, attention is called to gas sands because of the nature of the resistivity curve in these bodies. This condition is caused first by the fact that gas is compressible, with the result that gas sands are more susceptible to mud invasion and hence are more subject to variation of the salinity of the mud than are oil sands. A factor which may induce a high resistivity reading is the dryness of gas sands; that is, there is commonly little or no connate water present in the sands as compared, for example, to an oil sand which commonly is relatively high in connate water content.

(2). *Clean sand—conductive.*—When filled with salt water, the clean sand is very conductive, showing a low resistance, usually less than that recorded in shales. Especially is this true in resistivity curves with a large depth of penetration.

Distinction between oil, gas and salt water is often possible from the electrical diagram (Fig. 14). Gas should show the highest resistivity, oil next, and then salt water, which is conductive. However, the distinction between gas and oil-bearing formations is not always readily apparent. As for the self-potential curve, it is often observed that gas shows less values than oil, which, in turn, shows less than salt water. This is believed to be caused by the increase in the electro-osmosis effect with the increase in saline water content. In some instances this characteristic is sufficiently apparent to permit the location of the oil-water contact by inspection of the self-potential diagram alone.

B. *Dirty sand.*—Dirty sand can be defined as a sand which is fairly homogeneous but carries in the interstitial spaces, between the sand grains, fine particles of sponge-like or adsorbing material called colloids, usually classified as smaller than $\frac{1}{3{,}000}$ of an inch. The adsorbed saline water within the colloidal material has the effect of increasing the connate water content (observed by actual analysis), and therefore decreases the resistivity of an oil or gas sand. This

condition is always accompanied by a very large decrease in the permeability, as low sometimes as a few millidarcys, although the porosity may not be affected. Figure 12 is an example of such sand, and the adjoining table gives an analytical comparison between the clean and dirty sand. It will be observed that the self-potential effect is only slightly decreased if at all.

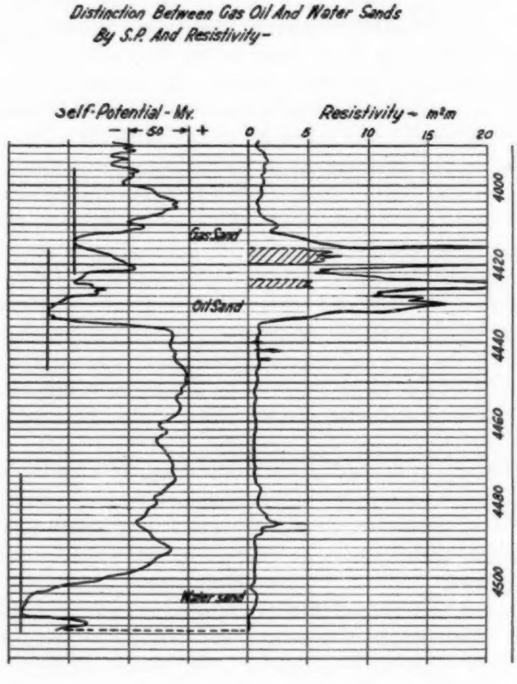


Fig. 14

C. *Cemented sand.*—Cemented sands can be defined as the rather heterogeneous sand containing cementing material of the non-spongy or non-adsorbing type, such as lime, silt, and mica. The presence of such cementing material usually lowers porosity and permeability considerably, particularly the latter. This type of sand can be recognized, however, by the abnormally low self-potential. Figure 15 is an example of such sands.

2. *Limestone—sandstone, et cetera.*—Dense, non-porous limestone

CEMENTED SANDS

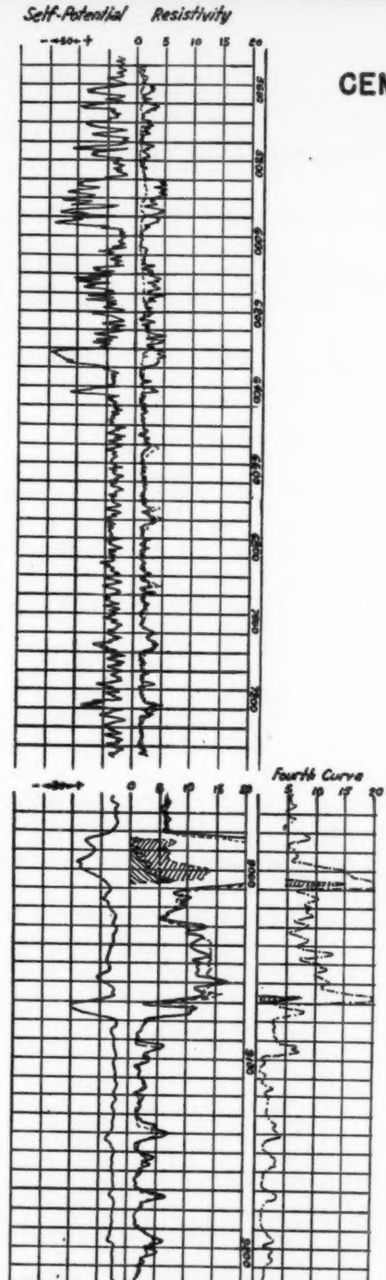


FIG. 15

shows extremely high resistivity values because it does not contain any connate water.

To recognize the various fluids in a porous limestone is not always an easy task as the porosity of limestone is something local and irregular throughout the bed.

The Salt Reaction

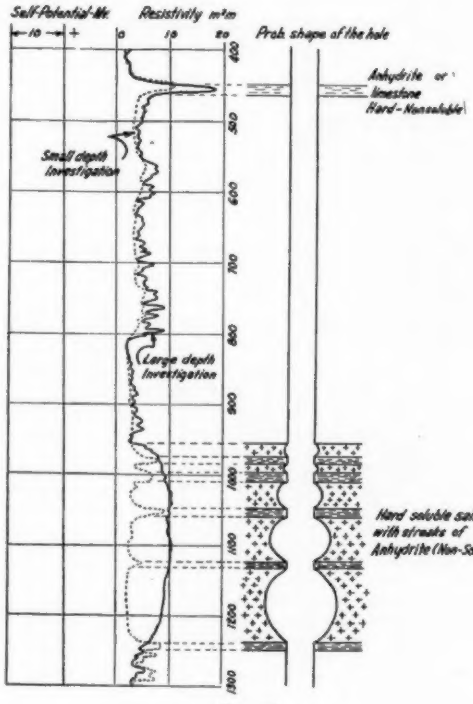


FIG. 16

Porous limestones containing oil will show high resistivities. Salt water in porous limestone will register much less resistivity, and the difference between oil and salt water, for a given limestone, will be found by comparing the relative resistivities of oil and salt water.

PART V

EFFECT OF SALT BEDS ON MEASUREMENTS

Salt in a solid form is a non-conductor. Therefore, in an electrical log the presence of a salt body will, in general, behave as in the pres-

ence of any resistive formation; that is, the presence of salt will show resistance on an electrical log.

Thin layers.—Thin layers of salt should record in the same manner as any thin resistant layer, such as limestone. In practice, it may happen, however, that, the salt being readily dissolved by the mud, the actual diameter of the hole is in excess of the radius of investigation, and the resistivity value will approach that of the mud (Fig. 16).

PART VI

FUTURE OF ELECTRICAL LOGGING

Although a remarkable advancement has already been made in the technique of electrical logging, it has by no means reached the end of its possibilities. During the first few years of application, it established an undisputed reputation as an ideal tool for correlation. At the same time, considerable experience was gained in the interpretation of fluid content of the formations, leading to the use of several resistivity curves for this purpose, in order to eliminate the effect of invasion of porous formations by water from the drilling mud.

More recently, it has been found that a very close and exact relationship exists between the electrical resistivity and the potential production of a porous zone. Obviously the determination, in this manner, of the recoverable oil in a given field has great possibilities for future development.

The self-potential curve also offers possibilities of a wider application, in the use of several curves recorded under different conditions. While the single curve allows a ready distinction between porous and non-porous formations, two or more curves, recorded at different pressures, provide a means of determining, in place, the permeability of the formation.

For example, if the differential pressure (hydrostatic head minus formation pressure) is increased by applying additional pressure on the mud column, the electro-filtration will increase in front of the more permeable formations, and if curves of self-potential are made at different pressures, it will be seen that the self-potential differential curve is very similar to the permeability curve, as shown by Figure 17. In practice, this differential self-potential curve is a measure of the permeability of the undisturbed formations, with respect to the fluids which they contain. Consequently, the permeability determined in this manner is a better guide to the behavior of a given formation under production or flooding conditions, than is the permeability determined on a core, for example. For the same reason, electrical permeability and core analysis may not necessarily agree.

As work progresses, new avenues for the application of electrical logging will be perfected, and it is hoped that the work by this study group will render the subject of electrical logging more familiar to its users and will stimulate interest for a more complete and intricate study of the subject.

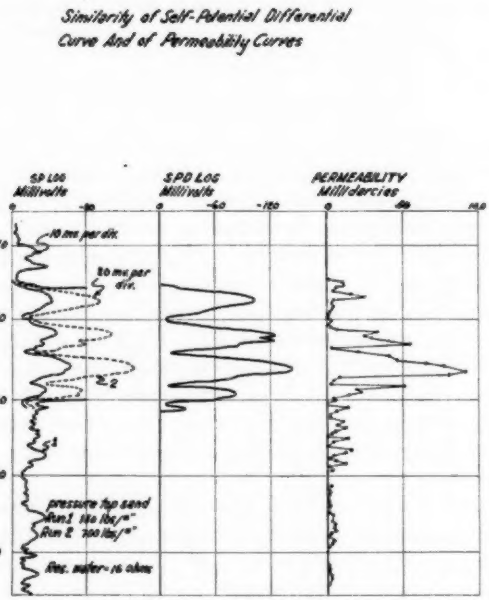


FIG. 17

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 23, NO 9 (SEPTEMBER, 1939), PP. 1314-1319

THE BASIS OF PRORATION IN TEXAS[1]

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ABSTRACT

The institution of proration is vital to the welfare of the oil-producing industry in the United States; yet its essential function is so commonly misinterpreted that its usefulness and even its continued existence are gravely menaced. Petroleum geologists are particularly concerned with the success of true proration and should not fail to understand its fundamental character.

Oil producers too generally regard proration as a form of curtailment designed to prevent overproduction of crude oil and thereby to secure and maintain higher prices. In contrast to this generally held concept, proration in Texas, where it has been applied most widely and drastically, rests solely on (1) the conservation laws for the prevention of physical waste of oil and gas, and (2) the police powers of the State for the protection of the citizen in his basic property rights. Even the provision for the "limitation to market demand," frequently denounced as "production control," is in fact fully justified as a means of preventing physical waste.

Proration in Texas, then, can be employed only to prevent physical waste. In accomplishing this purpose it neither supersedes nor suspends the "law of capture." Nevertheless, it ameliorates the excesses and inequities that have arisen out of the application of the law of capture in the past.

If the industry adopts an attitude that proration is to be used by the individual states or by the Interstate Compact to curtail production for the purpose of "stabilizing the industry" or "improving the price level," it will force the courts to condemn a concept which in preventing physical waste renders great service.

Recent discussions among oil producers, as reported in the current journals of the industry, emphasize how widespread is the view that one objective of proration is to insure satisfactory prices. "The fundamental purpose of proration is to secure an outlet for every well, no matter where situated, at a fair price." These are the words of a leading Mid-Continent operator, addressing the Board of Directors of the American Petroleum Institute last winter.

Proration can not safely be used as an agency for increasing price. The American Government with its aversion to production controls, will not long tolerate an organized effort by competing producers, except possibly farmers, to increase prices through curtailment of production.

Proration, as conceived and administered in Texas, where it has come to be most rigorously applied, is solely a measure for the prevention of physical waste in the production of petroleum. It functions through apportionment of the available outlet among competing oil producers and, at times when aggregate production exceeds total outlet, it restricts production. Even the provision for limiting produc-

[1] Presented by title before the association at Oklahoma City, March 23, 1939. Manuscript received, June 22, 1939.

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tion to market demand is designed solely to prevent physical waste. So zealous were the lawmakers of Texas in this connection that, in legislating against physical waste of petroleum, they expressly provided that "waste shall not be construed to mean economic waste." The true function of proration has been clearly defined time after time in the public utterances of Colonel E. O. Thompson, chairman of the Railroad Commission which administers the conservation laws of Texas. It is no mere coincidence that Texas' adherence to the Interstate Compact was specifically limited by Governor Allred and by Chairman Thompson to participation in measures for the prevention of physical waste of petroleum. Elimination of physical waste is the very essence of the conservation laws of Texas.

The nature of true proration, as practiced in Texas, may be glimpsed by reviewing briefly the development of the conservation laws[3] and practices of that State.

Texas, a State which produced oil as long ago as the year 1866, first adopted conservation laws in 1899, after oil production in the Corsicana field had become large enough to involve important waste. It was to prevent this obvious waste that the original legislation was enacted, and that the statutes were amplified by subsequent enactments in 1905, 1913, and 1917. In the latter year, the people of Texas, driven by their concern over wasteful methods of producing oil, went to the length of amending the constitution of the State (Section 5A-a, Article XVI), declaring that "the conservation and development of all the natural resources of this state . . . are each and all hereby declared public rights and duties and the Legislature shall pass all such laws as may be appropriate thereto." With this provision in the constitution itself, there could no longer be any doubt of the validity of the waste statutes of Texas. On this amendment and on the police power of the State the conservation regulations are based.

Uniformly the conservation statutes of Texas aim to prevent physical waste. The "proration laws," including the limitation to market demand, although carefully framed to maintain equity among competing producers, are essentially enactments designed to prevent waste. Texans would amend Herbert Hoover's "conservation is efficient use" to read "conservation is efficient production and use," with emphasis on "production."

Proration, in the sense of limitation of production on a uniform basis throughout an oil field, was first employed in Texas in the Yates field in 1927. The capacity of this field to produce oil increased so

[3] Robert E. Hardwicke, "Legal History of Proration of Oil Production in Texas," *Texas Law Review* (Austin, Texas, October, 1937). 99 pp.

rapidly following discovery that it soon far exceeded pipe-line outlet. At the suggestion of the principal purchasing company[4] which was also a producer in the field, and with the approval of the Railroad Commission, whose action was prompted solely by its desire to prevent physical waste, Yates field producers distributed on an equitable basis among wells capable of yielding perhaps 100,000 barrels per day, the total available pipe-line outflow of some 30,000 barrels per day. All leasehold properties in the field, including the properties of purchasing companies, were so restricted in production as to permit each to share ratably in the market.

In the following year, flush production in Winkler County was "prorated" under a formal order of the Railroad Commission, and since that time practically every flush field in Texas has been prorated. It was not until 1930, however, that Texas, following the lead of Oklahoma, limited the total production of the state by Railroad Commission order to an amount not to exceed the reasonable market demand. Exhaustive hearings had been held and numerous witnesses, qualified as experts, had appeared before the Commission to testify that underground waste is caused by non-uniform withdrawals from a natural oil reservoir, such as occur when one property remains shut in because of the lack of market, while another property, having access to the market, produces without restraint. Such production practice clearly dissipates reservoir energy, promotes irregular encroachment of bottom or edge water, sets up reservoir pressure gradients, and otherwise acts to diminish ultimate recovery. Incomplete recovery of the oil and gas content of the reservoir is recognized as a distressing form of physical waste.

Obvious as these facts are to the petroleum geologist, the courts were not immediately convinced of their validity. In July, 1931, a United States District Court held that an order of the Railroad Commission limiting production in the East Texas field to reasonable market demand was invalid, having no relation to physical waste, and declared that the testimony of geologists and other experts to the effect that dissipation of reservoir energy caused irregular advance of the water table, resulting in underground waste, was mere speculation, not acceptable as evidence in the Court. Deeply rooted in the mind of the Court was the suspicion that proration orders based on the theory that production in excess of market demand causes waste were merely "price fixing." In spite of the decision of the Supreme Court, in May, 1932, upholding the market demand statute in Oklahoma, it was not until February, 1934, and not until actual producing

[4] Humble Oil and Refining Company.

history in the field itself had abundantly proved the validity of the original contention of the experts, that the Federal District Court finally upheld an order of the Railroad Commission limiting production in the East Texas field to the reasonable market demand for oil from that field.

The long and involved history of court action over proration orders in the East Texas field demonstrates how completely the conservation regulations in Texas, including the proration laws, rest upon the prevention of physical waste. It reveals also how insidious and fatal to true conservation is any suspicion in the mind of a court that proration really seeks to control prices. It would be deplorable if the government or the public became similarly convinced that proration is a price-fixing device.

Proration in Texas does not nullify the law of capture. The law of capture attempts to give practical expression to the fundamental right of every owner to recover the oil which underlies his property. It assumes that this objective is accomplished when every producer enjoys equal opportunity to reduce his oil to possession, and it attempts to make this equality of opportunity uniformly attainable by decreeing that any oil produced from a well drilled within the limits of a given property belongs to the owner of that property. It is obviously a "rule of convenience" designed to make effective in an every-day world the more fundamental law of property that ownership of the subsoil vests in the owner of the surface.

Properly administered, proration protects each competing producer in his fundamental right to reduce to possession that part of the total recoverable content of the reservoir that originally underlay his property. But it restrains each producer ratably in his effort under the subordinate rule of convenience, to produce at maximum speed. In this fashion it may be said to modify the law of capture. Incidentally, it increases greatly the total volume of recovery from the types of reservoirs most common in Texas.

Perhaps the most valuable contribution to the welfare of the oil-producing industry that has come out of Texas' experience with proration is in the nature of a by-product rather than a primary objective. This contribution is the graphic demonstration that the East Texas field, restrained in its flow under the proration orders of the Railroad Commission, can be made to yield its oil without any concurrent dissipation of reservoir energy as measured by bottom-hole pressures. Perhaps no oil field had ever previously been operated on a permanent basis except at the expense of reservoir pressures. But East Texas has produced for years now in such fashion as conclusively

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Proration in Texas does not nullify the law of capture. The law of capture attempts to give practical expression to the fundamental right of every owner to recover the oil which underlies his property. It assumes that this objective is accomplished when every producer enjoys equal opportunity to reduce his oil to possession, and it attempts to make this equality of opportunity uniformly attainable by decreeing that any oil produced from a well drilled within the limits of a given property belongs to the owner of that property. It is obviously a "rule of convenience" designed to make effective in an every-day world the more fundamental law of property that ownership of the subsoil vests in the owner of the surface.

Properly administered, proration protects each competing producer in his fundamental right to reduce to possession that part of the total recoverable content of the reservoir that originally underlay his property. But it restrains each producer ratably in his effort under the subordinate rule of convenience, to produce at maximum speed. In this fashion it may be said to modify the law of capture. Incidentally, it increases greatly the total volume of recovery from the types of reservoirs most common in Texas.

Perhaps the most valuable contribution to the welfare of the oil-producing industry that has come out of Texas' experience with proration is in the nature of a by-product rather than a primary objective. This contribution is the graphic demonstration that the East Texas field, restrained in its flow under the proration orders of the Railroad Commission, can be made to yield its oil without any concurrent dissipation of reservoir energy as measured by bottom-hole pressures. Perhaps no oil field had ever previously been operated on a permanent basis except at the expense of reservoir pressures. But East Texas has produced for years now in such fashion as conclusively

to prove that reservoir pressures can be maintained indefinitely at a constant level if the rate of withdrawal be controlled to that end. In fields of this type (hydraulic control) reservoir pressures can even be restored to their original values, after being depleted by too rapid withdrawals, through progressive restriction of the rate of flow. This restoration of original pressures, after considerable depletion, has actually been accomplished in the Sugarland field in the Texas Gulf Coast region.

Next in importance, perhaps, among the benefits arising from this experience with proration in Texas is the proof that proration is in fact something more than a "price-fixing scheme." Early testimony of geologists and experts in courts and before conservation boards proved to be not mere speculation, as the first opinions of the Federal District Court judge charged. Texas' experience with proration has now amply demonstrated the validity of these ideas in their application to a great oil field, East Texas. An informed, enlightened viewpoint in the courts of justice is indispensable to true conservation and except for our East Texas experience such a viewpoint could scarcely be so firmly established even at this late date.

In oil fields with divided ownership, proration is essential to conservation and to maximum recovery. Without proration, retarded withdrawal rates can not be effectively enforced. If withdrawal rates can not be uniformly retarded, ultimate recovery is greatly diminished. The degree to which ultimate recovery can be increased by retarding the rate of withdrawal is not widely realized. The utility of extreme retardation has been emphasized in another paper.[5] Withdrawals of more than about 450,000 barrels of fluid daily deplete reservoir pressures in the East Texas field. Maximum ultimate recovery is obtained by maintenance of undiminished reservoir pressures. Therefore, withdrawals from East Texas, an oil field originally containing a volume of recoverable oil estimated at 3 or 4 billion barrels, must be distributed through a period of some 8,000 days, or more than 20 years, if maximum recovery is to be attained. Similarly, Sugarland, with original reserves estimated at from 60 to 70 million barrels, can produce only 5,000 barrels, or so, per day without depleting its reservoir pressure. For maximum recovery it should be operated on a basis of about 35 years producing life.

There is a widespread feeling that such greatly retarded withdrawal rates as are suggested above benefit only the exceptional field. In other words, it is contended that reservoir pressures can not

[5] Wallace E. Pratt, "Thirty-Year Oil Fields," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 22, No. 12 (December, 1938).

be maintained in the typical oil field, no matter how slowly withdrawal takes place. It may be suspected that this view contains an element of wishful thinking, although it is, of course, valid in the rare case of a reservoir completely under volumetric control (high gas-oil ratio, no hydraulic pressure.) We like to produce our oil rapidly because in so doing our investment returns to us promptly. That the life of the average oil field can be extended to 20 or 30 years of practically constant flow with attendant increases of both profit and total recovery may be debatable, but it can hardly be doubted that both profit and ultimate recovery will be augmented by reducing drastically withdrawal rates in effect in many flush oil fields today.

Proration is indispensable if withdrawals are to be uniformly retarded. Withdrawals must be uniformly retarded if ultimate recovery is to be a maximum. If ultimate recovery is less than a maximum, physical waste is involved. Physical waste in Texas is forbidden by the conservation laws, subject, of course, to the "rule of reason." This simple argument justifies proration, including limitation to market demand, and defines its legal basis in Texas.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 23, NO. 9 (SEPTEMBER, 1939), PP. 1320-1351, 22 FIGS.

STRUCTURAL AND MAGMATIC PROCESSES IN THE ISOSTATIC LAYER[1]

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ABSTRACT

In the continental areas the outer 60 miles of the earth is herein referred to as the isostatic layer. This is subdivided from the surface downward as follows: a 10-mile granitic and sedimentary layer, a 20-mile intermediate layer of basic crystalline rocks, and a 30-mile layer of tachylyte. The uppermost and intermediate layers are generally referred to as the crust.

Below the isostatic layer the earth is cooling and shrinking. Stresses in the isostatic layer are piled up until the breaking point is reached when these stresses are relieved by deformation of the crust. Mountain ranges are folded up and geosynclines are downwarped. Approximate isostatic balance is maintained throughout this series of events.

Great masses of sediments will be deposited in the downwarps. A 2,000-foot basin will hold 12,000 feet of sediments because the deposited material is $\frac{5}{6}$ as heavy as the material below that is replaced during periods of isostatic adjustment. The trough will be further deepened by rise of the level of base level. This is brought about by displacement of the sea water as the land masses are deposited in the ocean basins. Downfolding of the geosynclines will also occur as a result of geothermal changes. It is estimated that the rate of erosion exceeds the rate of thermal changes within the earth so that during a period of erosion the isogeotherms will be turned up. Downwarping will follow base-leveling merely as the isogeotherms return to normal. This may amount to as much as 1,000 feet and may be added to the downwarping brought about by crustal collapse and deepening resulting from the rise of the level of base level. In general about 9,000 more feet of sediments may be assigned to the basin through deepening brought on by thermal and base-level changes, making a total of 21,000 feet of beds.

Collapse of the crust at this time will fold this prism of sediments into a great mountain system. The beds must be downfolded about six times as much as they are upfolded in order to maintain isostatic balance. Compressive stresses will be dominant and the types of structures that will be formed are close folds, overturned folds, and thrust faults. Erosion of the mountain system will be accompanied by periodic vertical thrusts. These are effected as a result of isostatic adjustment. Compressive stresses will still be present but they will be secondary and brought on as only incidental to the vertical movements.

Final erosion of this mountain system will leave the isogeotherms turned up. As the isogeotherms return to normal the resulting shrinkage will form a basin right where the high mountain range once stood. Crustal collapse will deepen the downwarp already begun and the new series of sediments will be separated from the first by a very marked angular unconformity.

Another series of events may be started during the late stages of erosion. The viscosity of the subcrustal tachylyte layer may be reduced, by removal of overlying rock pressures and slight rise of temperature, to the point where crystals of olivine may begin to form in it. Once this process of fractional crystallization commences it will gain in momentum and a magma will be formed. Convection currents will stir the liquid body and it will work its way upward by selective fusion. When it reaches the zone of fracture it will be intruded and extruded. Repeated intrusions and extrusions will occur until the magma finally will be solidified. Cooling of the magmatic zone will cause shrinkage and downwarping, and this area once again will become the site of a geosyncline.

[1] Read before the Society of Exploration Geophysicists at the annual meeting in Oklahoma City, March 23, 1939, and before the Tulsa Geological Society, February 20, 1939. Manuscript received, June 15, 1939.

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The earth is ever in the process of change. Land masses rise high above the oceans and are worn down to water level only to rise again. Great quantities of magma are intruded into the crust and poured out onto the surface. Large sections of the crust are downwarped and filled with sediments. Other sections are crushed into high mountain ranges. These structural and magmatic changes present innumerable problems many of which extend beyond the field of geology. In order to study them it is necessary to combine the work of the geologist and the geophysicist. Only by uniting the views of both groups of scientists can we ever hope to attain a true understanding of the earth and the processes to which it is subjected.

This planet is a very rigid body to the seismologist and a rather mobile globe to the geologist, yet these two views are compatible. The seismologist looks at the earth as a whole while the geologist occupies himself principally with crustal changes. The data on earth tides, precession of the equinoxes, and seismic waves all indicate that the rigidity of the earth is greater than that of steel. The geologic data regarding accumulation of great bodies of sediments with the attendant sinking of the basins to accommodate these deposits, folding of mountain ranges and erosion to base level, movement along fault planes, intrusion and extrusions of great lava bodies, all tend to emphasize mobility.

The geologist can not disregard the information compiled by the seismologist and geophysicist, and neither can the seismologist and geophysicist neglect to make their ideas conform to the facts of geology. In an earlier day, the geologist could explain that magmas came from a liquid subcrustal layer. Today, no credence is given to a liquid substratum although a liquid core is quite probable. Seismic observations show that transverse waves are carried down through the earth to a depth of about 1,850 miles before they are damped. At this level there is a very marked discontinuity as noted by reduction in velocity of the primary waves. The seismologists are therefore very strongly inclined to regard the core of the earth as liquid and its radius just a little more than half that of the whole earth.

Above the core, the earth is solid. It may or may not be crystalline, but theoretical studies made by the geologists tend to show that a reasonable pursuit of the course of events of the earth's early history indicates that most of it is crystalline, and whatever glass is present should be confined within the upper 60 or 70 miles. It is further noted that the existence of deep-foci earthquakes[3] indicates[4] considerable

[3] B. Gutenberg and C. F. Richter, "Depth and Geographical Distribution of Deep-Focus Earthquakes," *Bull. Geol. Soc. America*, Vol. 49 (1938), pp. 249–88.

[4] Andrew Leith and J. A. Sharpe, "Deep-Focus Earthquakes and Their Geological Significance," *Jour. Geology*, Vol. XLIV (1936), pp. 877–917.

strength down as far as 700 km. That portion of the earth from the liquid core to the base of the 60-mile zone, is relatively homogeneous as determined by the seismic velocities, and according to the application of the principles of magmatic differentiation by J. H. L. Vogt, N. L. Bowen, Harold Jeffreys, L. H. Adams, and others, it is composed of dunite, a monomineralic rock of olivine, and is referred to as the dunite layer.

The outer 60 miles of the earth is very complex. The acidic rocks are confined almost entirely to the continental areas; the oceanic regions, with minor exceptions, are underlain by basic rocks. Under the continents, to a depth of approximately 10 miles, the rocks are largely sediments and granites. Below this 10-mile layer is another referred to as the intermediate layer which is from 15 to 20 miles thick and is thought to be composed of rocks more basic than granites, perhaps gabbro with some diorite in the upper part. It is also very interesting to note that the principal discontinuity in seismic wave velocity, the Mohorovičić discontinuity, occurs at the base of the intermediate layer. The oceanic regions are thought to be underlain by crystalline basaltic rocks down to depths of 10 or 20 miles.

What is believed to exist immediately below the crystalline layers of both the continents and oceans is purely speculative. Daly's[5] supposition that the subcrustal layer is glassy basalt or tachylyte seems to be a very logical basis from which to work. It offers a reasonable explanation for so many of the vexing problems of geology, although it should be pointed out that as yet there is no definite seismic evidence for the existence of such a layer.

The tachylyte layer is thought to be universal and extends from the base of the crystalline intermediate layer to the top of the crystalline dunite layer. It is bottomed at a depth of about 60 miles which is close to the level of isostatic compensation of Bowie,[6] and the level of no strain of Jeffreys.[7]

As the present paper deals principally with the continental segments it might be well to summarize briefly the supposed earth divisions under the land areas. A dunite layer 1,800 miles thick rests on the liquid core. The top of this layer is close to the level of isostatic compensation and approximately at the level of no strain. The dunite layer is overlain by the tachylyte layer. It is 30 miles thick and its upper surface is marked by the Mohorovičić discontinuity. Next in

[5] R. A. Daly, *Our Mobile Earth*, 1929 edition, p. 92.

[6] Wm. Bowie, "Investigations of Gravity and Isostasy," *U. S. Coast and Geodetic Survey Special Publication No. 40* (1917), p. 112.

[7] Harold Jeffreys, *The Earth*, 1929 edition, p. 282.

order is the intermediate layer about 20 miles thick. It is succeeded by the granitic and sedimentary layers, which together have a total thickness of about 10 miles. The layers above the Mohorovičić discontinuity are usually referred to as the "crust." The entire outer 60 miles of the earth, in this paper, is termed the "isostatic layer."

CRUSTAL COLLAPSE

Folding and warping of the superficial earth layers indicate quite conclusively that the crust has been shortened. This is explained by collapse of the crust on a shrinking interior. The temperature of the isostatic layer remains essentially constant while the interior cools and shrinks. The isostatic layer is kept in contact by the pull of gravity. Stresses in the crust grow until the breaking point is reached when relief is accomplished by folding and faulting. Such a geological revolution would probably mark the close of an era.

The process is cyclic. The interior continues to shrink. Stresses in the crust are built up again to the breaking point, and relief by crustal adjustment will mark the close of another era.

Jeffreys has shown that there has been enough shrinkage to account for five periods of major readjustment. He stated,[8]

> An average cooling of about 500°C. is to be expected through depths down to 400 km. This, with a volume contraction of 5 per cent would imply a reduction of 20 km. in radius and therefore of 130 km. in circumference. To this should be added allowances for contraction in crystallization and for loss of volume due to extrusion of volatile constituents, especially water. The cooling below the oceans is probably greater than below the continents. The uncertainties in all the determinations, however, are such that we can only say that the compression of the crust is of the order of 200 km.; it may easily be half or twice this. . . . If the shortening of the crust is 200 km. the reduction in the area of the earth's surface is 5×10^{16} cm^2. The areal compression needed to account for all the mountains of the globe was about 2×10^{16} cm^2, subject to some increase to allow for old ranges already denuded away (and probably not yet known or included in the calculations). The available compression would therefore appear ample, and perhaps indeed embarrassingly superfluous, if the geological estimates of the observed compression had not recently been so much increased.

If the radius of the earth were shortened 3 miles the areal reduction would be 300,000 square miles. Areal reduction of such magnitude would account for 10,000 miles of mountains with 30 miles of tangential shortening. This would be quite sufficient to produce most of the mountain systems that have been formed during any one era, especially when it is considered that shortening will take place through the entire 60-mile layer, and not merely in the superficial layers. But

[8] Harold Jeffreys, *The Earth*, 1929 edition, pp. 281–95.

crustal shortening is not the only means by which mountains may be formed. As will be shown below great elevations also may be produced by magmatic processes.

ISOGEOTHERMS

The surfaces of equal temperature within the earth are termed isogeotherms. Normally, they are considered to be parallel to each other and to the geoid surface. Bending or folding of the crust will depress or arch them after which they will tend to return to normal. The rate of return is very slow as indicated by the conductivity of rocks and the rate of cooling of the earth since its formation. Adams[9] and Jeffreys[10] have stated that the earth has cooled but little below the temperature of crystallization at depths lower than 450 miles, and that the average amount of cooling in the upper layers since formation has been about 500°C. It is apparent that only the outer layers have been cooled by any considerable amount and the average rate of heat loss is exceedingly slow.

The rates of mountain building and denudation are much more rapid than the rate of earth cooling. Mountain ranges have been folded up and reduced to base level during a period or two of geological time, a matter of tens of millions of years, while the cooling of the earth has gone on for about 2 billion years. Temperature adjustments in the crust have therefore lagged far behind folding and erosion.

The isogeotherms will be turned down during loading of a geosyncline and arched up during the erosion of a mountain system. The differences in elevation effected by isogeothermal changes will be considerable. According to the calculations of Bowie[11] the isogeotherms will be bent out of normal by as much as 250°C. in the 60-mile isostatic layer. Using the coefficient of expansion for marble he estimates that the increase of elevation produced by a temperature rise of 250°C. will be 2,850 feet. The temperature variations determined by the writer are much less than those calculated by Bowie, but are still large enough to be quite important. They do not exceed 75° to 100°C. so Bowie's elevation differences are reduced from 2,850 feet to about 1,000 feet.

ISOSTASY

The earth's crust is essentially in a state of balance. Regions which are high are compensated by being composed of low-density rocks, and regions which are low are underlain by high-density rocks. The

[9] L. H. Adams, "Temperatures at Moderate Depths within the Earth," *Jour. Washington Acad. of Sci.*, Vol. 14 (1924), p. 465.

[10] Harold Jeffreys, *The Earth*, 1929 edition, p. 281.

[11] William Bowie, *Isostasy*, pp. 250–51.

sedimentaries and acidic crystalline rocks are concentrated in the continental masses and the basic rocks are found almost exclusively in the oceanic areas. Washington[12] stated,

> The average density of igneous rocks of a region varies in the opposite sense as the average altitude. The results of the study, therefore, harmonize with and corroborate the theory of isostasy.

Johannsen came to a similar conclusion from a study of the color ratios of American and European rocks. The average elevation of North America is higher than that of Europe. He wrote,[13]

> North American rocks are shown to be universally lighter in color (and therefore also in density) than European rocks of the same kind.

He drew curves for granites, granodioritic granites, rhyolites, gabbros and basalts, and almost without exception the North American curves were higher than the European curves, showing a greater amount of the lighter-colored minerals in the American rocks than are present in the European rocks.

It is now recognized that mountain ranges are not extra loads on the crust nor are the ocean basins evidence of a deficiency of crustal material. Nor is it true that the crust has no strength at all. The amount of strength possessed by the crust is indicated by the size of the gravity anomalies. A few of them are quite large, suggesting some local abnormality, but on the average the isostatic anomalies are 15 per cent out of perfect adjustment.[14]

Anomalies are continually being produced by erosion and deposition. Mountains are unloaded and isostatically adjusted by uplift while basin segments are loaded and corrected by sinking.

The quantity of sediments which may be piled into a basin will depend upon the relative density of the sediments and the density of the material that is displaced below. Sedimentary rock ranges in density from 2.4 to 2.8, and the heavier material below that is displaced during periods of isostatic adjustment, ranges in density from 3.0 to about 3.4. The ratio is approximately 5 to 6. This means that for every 600 feet of sediments that are piled into a basin, 500 feet of material will be displaced below. After isostatic adjustment, a layer of beds 600 feet thick will leave the bottom of the basin 100 feet higher than it was before sedimentation. It will be necessary to put 6,000 feet of sediments into a 1,000-foot basin in order to fill it.

[12] H. S. Washington, "Isostasy and Rock Density," *Bull. Geol. Soc. America*, Vol. 33 (1922), pp. 375–410.

[13] Albert Johannsen, "Comparative Color Ratios of American and European Rocks," *Jour. Geol.*, Vol. 36 (1928), pp. 283–86.

[14] William Bowie, *Isostasy*, p. 76.

BASE LEVEL

The filling of basins and reduction of mountain systems are accompanied by changes in base level. The history of the earth bears chapters of widespread mountain building and general uplift, followed by long periods of erosion and general denudation. The land masses are moved into the sea. The water is displaced and the ocean level rises. The process is gradual so the change is noted as encroachment of the seas upon the land, oftentimes referred to as a rising strand line. The oceanic areas are about three times as extensive as the continental areas; therefore the rate at which the strand line will rise is about one-third of the rate at which the land areas will be reduced.

The land areas today have an average elevation of about 2,100 feet.[15] If all of this were sliced off and dumped into the oceans the water level would rise about 700 feet. The actual amount of rise resulting from the ordinary processes of erosion would be about half of this amount because the seas would encroach as the denudation progressed. By the time base level is reached on our present continents, the level of the sea will have risen only half of the 700 feet or a distance of 350 feet.

This is only part of the story since the upland areas have already been greatly affected by erosion. High mountains, such as the Himalayas, Alps, Rockies, and Andes, have been eroded to such an extent that the average elevation of their valleys is only about one-fourth the average elevation of the mountain peaks. Probably, it would not be far wrong to consider that the reduction of the continental masses has already progressed about half way. It follows, then, that from widespread uplift to widespread denudation the level of base level may rise about 700 or 800 feet.

FUNDAMENTAL FACTORS OF CRUSTAL DEFORMATION

Consideration of the preceding exposition denotes that there are four basic factors that must be considered in a study of mountain systems: (1) the collapse of the crust on a shrinking interior producing mountain systems and geosynclines; (2) adjustment of isogeotherms following periods of folding and periods of extreme erosion; (3) isostatic adjustment during crustal collapse and during all stages of erosion and deposition; (4) change of the level of base level.

HISTORICAL COURSE OF A MOUNTAIN SYSTEM

This history of a mountain system begins with the deposition of sediments in a geosyncline. Some of the large regional downwarps

[15] H. S. Washington, *op cit.*, p. 375.

were more or less elongate and bounded by high land areas. Such were the Appalachian and Cordilleran geosynclines. There were also broad shallow basins bounded on only one side by high land areas and on the other side by low-lying areas, such as some of the inland basins, for example, the broad Cretaceous sea of the western interior. Others may have been far from the areas of erosion and surrounded partly by deep water such as the Gulf Coast region today. In general, a geosyncline may be considered as any large area of sedimentation, no matter what its shape, or how far it is removed from the areas that supply its sediments.

The nature of the sediments in a geosyncline indicate clearly that the troughs must have been quite shallow throughout most of their existence. Undoubtedly, they were depressed as they were filled, and the amount of depression can be measured by the great thicknesses of beds found in them. The Ouachita geosyncline[16] of southeastern Oklahoma received from 25,000 to 30,000 feet of sediments, and other basins, such as those in California[17] and southeastern Canada,[18] are estimated to have been filled with sedimentary rocks more than 40,000 feet thick.

Sinking may have been gradual or periodic. The strength of the crust and the unconformities in the rock series strongly favor periodicity, yet there may have been times when sinking was continuous and gradual.

Crustal warping alone may form a geosyncline 2,000 feet deep. The total amount of folding may be 2,000 feet but the basin may never have had that depth at any time during its existence. Sedimentation would keep pace during the long period of sinking. A basin of this size is not an exaggerated supposition. The Gulf Coast embayment is several thousand feet deep and many thousands of feet of sediments have already been laid down in it.

The geosyncline is assumed to be approaching isostatic balance during the course of its formation. Even as the basin is being downwarped it is being overloaded by the deposition of sediments. Overloading will continue until the breaking point is reached and adjustment will occur. The basin will be depressed by some amount in addition to what would have established isostatic adjustment due to crustal warping alone. Sinking will not, of course, be even and regular

[16] H. D. Miser, "Structure of the Ouachita Mountains of Oklahoma and Arkansas," *Oklahoma Geol. Survey Bull. 50* (1929), p. 7.

[17] J. A. Sharpe communicated personally that seismic reflections have been received from a depth of 40,000 feet in the Ventura Basin of California that are believed to have come from sedimentary beds.

[18] L. V. Pirsson and Chas. Schuchert, *Outlines of Historical Geology* (1924), p. 494.

throughout, but the general direction of the movement will be downward.

The greatest thickness of sediments will be in the deepest part of the basin in the epicontinental seas, and at some distance from the shore line in those basins which are on or close to the continental shelves. That portion of the basin which has the greatest load will be depressed the most and the greatest thickness of sediments will be deposited in approximately the same area after each period of adjustment.

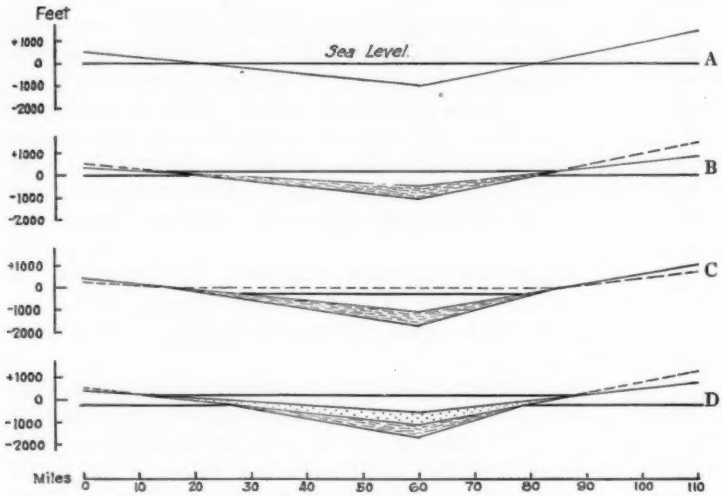

FIG. 1.—A. Cross section of basin before sedimentation.
B. Sedimentation has displaced water and widened area of deposition.
C. Isostatic adjustment has deepened basin and reconfined water. Marginal sediments are now exposed to erosion.
D. Second series of sediments overlaps unconformably on first series of sediments along the margins of basin.

The water in the basin is shallowed and extended as it is displaced by sediments (Fig. 1). Adjustment will deepen the trough and reconfine the water, exposing the marginal deposits to erosion. As the basin is filled during the second stage of deposition the water will again be displaced and spread out. That part of the basin which was subjected to erosion will be covered by the second group of beds and their contact with the first series will be unconformable. The complete series of sediments will be marked by a number of such unconformities, each one recording a periodic sinking of the basin.

Normal faulting will occur along the margins of the basins (Fig. 2). Rock can not be stretched very far before breaking. The deepest part of a basin which has received from 20,000 to 25,000 feet of sediments will have been depressed 4 to 5 miles. A section of the crust 150 miles across which has been bent down a maximum of 5 miles will have been stretched about $\frac{1}{3}$ mile. This accounts for sufficient horizontal dis-

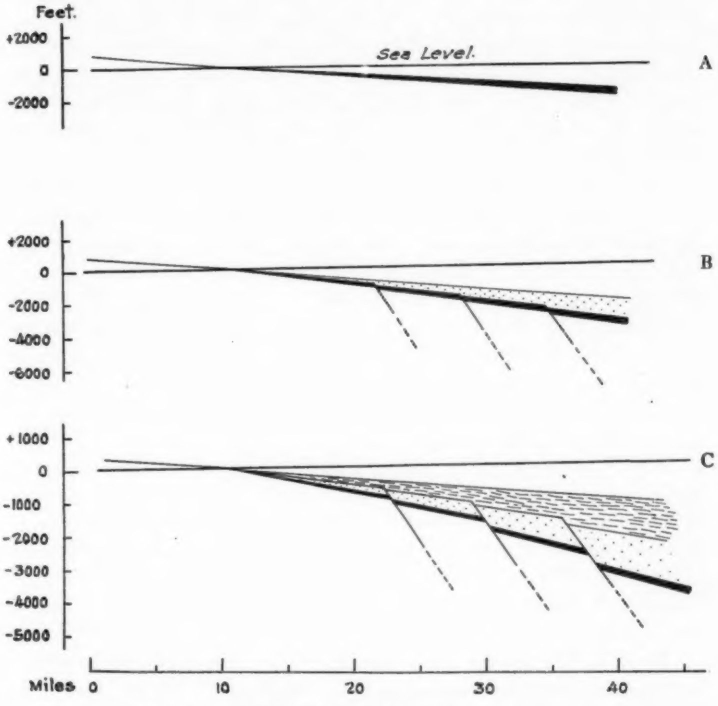

FIG. 2.—A. First series of beds is deposited in basin.
B. Sinking of basin has faulted first series of beds which is overlapped unconformably by second series which is not faulted.
C. Second stage of sinking has faulted the beds again. First beds have been faulted twice, second series of beds has been faulted once, third series is not faulted and overlaps the others.

placement to allow for the formation of many normal faults of great magnitude. The angle of dip will be between 45° and 90° into the basin, although faults dipping away from the basin may also be developed. The faults will be marginal because the adjacent land masses will be rising due to unloading, and the basin area will be

sinking as a result of loading. There will be pulling away from the margins in both directions.

Movement along the fault planes will be periodic in accordance with periodic isostatic adjustment. Once breaks have been made they will become planes of weakness and the locus of movement for later adjustments. The lower beds will therefore suffer greater displacement than the upper beds since they will experience a larger number of displacements. The theory of fault scarps along the margin of geosynclines has already received practical application. Harlton[19] conceived the idea of fault scarps along the outer margin of the Ouachita basin. He found it a very logical explanation for the high land area which must have existed at one time to supply the coarse sediments occurring there.

Only part of the downwarping of a geosyncline is caused by crustal shortening during crustal collapse. Some of it may be due to the lowering of the isogeotherms and to the rise of base level. It was indicated that the amount of deepening brought about by heat adjustment may be 800 to 1,000 feet, and that resulting from a rising strand line, 700 or 800 feet. If a combination of both would produce a sinking of 1,500 feet in addition to the 2,000 feet of crustal warping, there would be room in the basin for 9,000 feet more of sediments. The total thickness of beds would be 21,000 feet which is about the quantity found in the Ouachita geosyncline.

When the basin is full, the top beds will be at or close to base level. Were this not the case, further erosion would cause an additional rise in the strand line and the process would continue until equilibrium is reached. At just about this time the crust may collapse on the shrinking interior. If not, there may be a long period of quiesence until the crustal adjustments do occur to compress the sediments into a mountain system.

Most of the shortening will be taken up by the sedimentary prisms because they are the weakest parts of the crust. Their cross sections may be reduced by as much as one half. A basin 150 miles across may be shortened until it is only 75 miles wide.

A mountain system which is folded up must be also folded down. To maintain the isostatic balance it is necessary to fold down the basin about 6 miles for every mile of upfolding. If the basin contains 20,000 feet of sediments, and is in isostatic adjustment before folding, the bottom will have been lowered 4 miles during deposition. It would require an additional depression of 6 miles to build up a moun-

[19] Bruce H. Harlton, "Stratigraphy of the Bendian of the Oklahoma Salient of the Ouachita Mountains," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 22 (1938), p. 863.

tain range a mile high. This would put the bottom of the basin down to a depth of 10 miles when adjustment is completed.

During the folding, the isogeotherms will be depressed at a much greater rate than they could be corrected by ordinary heat conduction. The rise of the isogeotherms will record the heating and expansion of the segment containing the mountain system. Expansion of the order of 1,000 feet would occur as the isogeotherms returned to normal.

Another item which has not yet been expressed quantitatively is the heat developed by friction during the folding and crushing of the sedimentary prism. It may be of importance, and the resulting expansion would add to the height of the system.

Tangential compressive stresses will be dominant when the crust is refitted to its foundation. The large amount of shortening which will occur in the geosynclinal prisms will develop intense crumpling, overturned folds, and thrust faults.

After the mountain system is formed and crustal equilibrium is established the principal direction of movement will be vertical. Erosion of the highlands will upset the isostatic balance and the adjustment will be upward. Even though the segment will be pushed upward to reëstablish the balance of isostasy, the beds in the mountain system will be under intense compressive stresses throughout most of their history. The downfolded sedimentaries will be continually crumpled and faulted as they are pushed up through an area about one-half of that occupied by the beds in their undistorted state.

Deep canyons will be cut into the newly formed mountains carving out ridges and peaks. The removal of so much rock should be sufficient to make adjustment necessary and the peaks will be pushed high into the air during the first and probably the second stage of isostatic adjustment. The highest elevations in a mountain range will be formed at some time after the origin of the system and not at the time of the initial building.[20]

In order to lower a mountain range about 1 mile it is necessary to remove 6 miles of rock. For each mile of reduction there will follow an upthrust of $\frac{5}{6}$ of a mile caused by the introduction from below of heavy material to bring about a state of isostatic balance.

By the time erosion has carried the surface down to base level the isogeotherms in this segment of the earth will be above normal. The rate of erosion is believed to be much greater than the rate of temperature correction through conduction. While the area is lowlying, a new geosyncline could be formed by rock shrinkage as the

[20] Harold Jeffreys, *op. cit.*, p. 283.

isogeotherms return to normal. As noted above, such a basin could be about 1,000 feet deep. If a period of crustal collapse did not occur at this time a broad basin would be formed bounded by low-lying land areas. This would be an ideal place for widespread limestone deposition, and a 1,000-foot basin could receive as much as 6,000 feet of sediments. The point to be emphasized is that a mountain system which has been base leveled can become the site of a new geosyncline merely as a result of temperature adjustments.

The area will be down folded when crustal collapse does finally occur. It is now an earth segment of strength rather than weakness as it was when loaded with sediments. Now it is underlain by dense rocks which are either igneous or metamorphic. Most of the sediments will have been removed by erosion, and those that are left will probably be metamorphosed. Furthermore, much of the rock which was carried from this area will in all probability be deposited in the basins which were formed as foredeeps to the mountain system. The adjacent regions will therefore be the weak segments and undergo distortion in order to relieve the stresses applied to this portion of the earth.

MAGMATIC FORMATION

A magma may be formed by simply raising the temperature of a rock mass until it becomes liquid. With dry melts this temperature may be as high as 1,300° to 1,500°C.; but magmas are solutions of minerals in minerals, and not dry melts. Volatile constituents are also present and they are referred to as mineralizers. The volatile constituents are usually water vapor, sulphuretted hydrogen, hydrofluoric acid, carbon monoxide, carbon dioxide, sulphur dioxide, hydrogen, nitrogen and oxygen.[21]

Magmas containing high percentages of mineralizers may be liquid at relatively low temperatures. Acidic magmas ordinarily contain a higher percentage of mineralizers than are found in the basic liquids, consequently are more fluid. This is largely due to the method by which each magmatic type originates. Crystallization in a magma proceeds in the order of solubility. The least soluble minerals come out first and these ordinarily are the basic minerals. As crystallization proceeds the residual magma grows increasingly acidic. At the same time the percentage of mineralizers in the residual magma is increasing. As the amount of residual magma diminishes the relative amount of mineralizers increases. Their quantity remains essentially constant until the late stages of crystallization are reached.

Basaltic lavas have been able to move under their own weight at

[21] G. W. Tyrrell, *The Principles of Petrology* (1926), p. 51.

600°C.,[22] and acidic rocks such as pegmatites and silexites are believed to have been formed at temperatures as low as 200° to 300°C. Any one of these rocks after crystallization and after the loss of mineralizers would have to be raised to 1,300°C., or more before it would again become mobile.

The supposition that the subcrustal layer is composed of tachylyte implies that mineralizers are in solution. This layer is a very viscous glass but it is not fluid. It is only potentially fluid. The evidence accumulated by a study of seismic waves proves quite definitely that it responds to short time stresses as if it were solid even though its temperatures are quite high. The top of the layer is 870°C. and the base is 1,270°.[23] At these temperatures basaltic lavas at the surface are very mobile.

Pressure increases the crystallization temperatures of minerals and also increases the viscosity of glass. With depth, the crystallization temperatures increase about 6°C. for each mile. Crystallization in the tachylyte layer is controlled by crystallization temperatures of the minerals, but more so by the solubility of each, their degree of saturation, and the degree of molecular freedom which may exist. The temperature of the tachylyte layer may be only a few degrees below the temperature at which crystallization may start. A rise in temperature of a few degrees or a decrease in overlying pressures, or both, may reduce the viscosity to permit enough molecular movement to start the formation of crystals.

Erosion of an uplifted area may both reduce the pressure and raise the temperature. The overlying pressure being lowered as the rocks are removed, isostatic adjustments will cause the isogeotherms to bend upward. Heat developed by friction during movement will also be of assistance. These changes may reduce the viscosity enough in that portion of the tachylyte layer immediately underlying the area being eroded, to initiate crystallization. The viscosity may still be very high, yet low enough to permit small crystals of olivine to form. The mineralizers would not be used up and their increasing percentage would tend to reduce the viscosity of the remaining mass, which by the crystallization of the mafic minerals, would grow more and more acidic. The viscosity of the remaining material is thus being continually reduced. The process once started will gain in momentum and in time the mass may become sufficiently fluid to be stirred by convection currents.

[22] A. L. Day, "Some Causes of Volcanic Activity," *Smithsonian Rept. for 1925*, p. 258.

[23] L. H. Adams, *op. cit.*

Once a magma is formed it will work its way upward mainly by solution and selective fusion.[24] The most soluble minerals in the overlying rocks will be dissolved. The less soluble ones will sink through the magma and collect in the lower part of the basin.

The heat generated by radioactive materials concentrated in the magma will aid in melting and dissolving the overlying rock. What heat may be developed from this source will help to expand, bulge, and fracture the overlying rocks, opening avenues for the intrusion of apophyses.

An earth segment which contains a magma will be one of low strength. The abnormally high temperatures and the large amount of liquid will permit isostatic adjustments to be made rather easily. Such an area may be subjected to continuous vertical movements during long periods of time.

A magmatic segment probably will be composed of low density material. There are several reasons for this. The first is that temperatures are high and expansion of rocks reduces their density. The second is that the liquid and dissolved gases may expand as they work their way upward into areas of lower pressures. The third is that much crystalline material will have been converted into liquid resulting in an increase in volume of 6 to 10 per cent. The fourth is that magmatic differentiation by fractional crystallization produces a rest-magma, which is acidic, granitic, or granodioritic in character and of lower density than the original magma. This low density magma may be concentrated by tangential compressive forces. Crustal shortening will reduce the horizontal cross section and elongate the vertical cross section. There will be upfolding, and also downfolding in order to maintain the isostatic balance. Crustal distortion under these circumstances could easily be of such magnitude as to produce a large mountain range. Subsequent erosion may in time expose its granitic core.

The movements in a magmatic segment may be gradual and continuous for long periods of time, periodic, or oscillatory. The resistance to movement is low when the temperatures are high and a large amount of liquid is present. Movements may then be gradual and continuous. With a higher degree of viscosity the movements may become periodic. Oscillatory movements suggest upward and downward action repeated several times. This may occur when the magma has reached the zone of fracture in its upward journey. At this stage of the process some of the liquid will be intruded into the crust as dikes, laccoliths, and sills, and part of it may be extruded

[24] N. L. Bowen, *Evolution of Igneous Rocks* (1928), pp. 315–20.

upon the surface as flows and tuffs. Crystallization and solidification of the intruded and extruded rock will reduce its volume. The sinking resulting from this shrinkage may be of the order of several thousand feet. At the same time the change from liquid to solid will seal the cover over the magma. The heat brought up from below by convection currents and the heat generated by the radioactive materials concentrated in the residual magma will be confined to the magma and the surrounding rocks. The increased temperature will cause expansion of the rocks in the roof overlying the magma; perhaps enough to fracture the roof and induce a second period of intrusion and extrusion. There will follow a second period of rapid cooling, crystallization, and shrinkage, and resealing of the magma. As a matter of fact, the magma probably would never solidify if there were not repeated intrusions and extrusions in order to dissipate the heat.

When the magma has finally become solidified most of it will be crystalline. The relatively small amount of extruded rock that may have solidified as glass is hardly of importance if reckoned on a percentage basis.

The amount of expansion and contraction as a result of heat and phase changes alone will account for 2 or 3 miles of vertical movements as it can reasonably be assumed that the vertical dimension of the magma was of the order of 30 miles at the time of its greatest extent. The vertical movements brought on by lateral compression and isostatic adjustments may be of the order of tens of miles.

The area finally will be reduced to base level. Subsequent cooling down to normal temperatures in the underlying layers will cause enough shrinkage to form a new basin. This magmatic segment will become the site of a new geosyncline.

COURSE OF EVENTS SHOWN DIAGRAMMATICALLY

A series of diagrams is used to show the course of events in the history of a mountain system. All the processes described are carried to completion. This does not necessarily imply that they are completed in nature. In fact, they may go only part way, stop and begin again, or be reversed. If it is possible to fit them into the history of any region it is not necessary that they should be applied in their entirety, or even in the order described.

The area chosen for scale is the Ouachita Mountains in southeastern Oklahoma and southwestern Arkansas. This mountain system was taken because its size, thickness of sediments involved, and the amount of crustal shortening which has taken place have been fairly well determined by such men as H. D. Miser, C. W. Honess, T. A.

Hendricks, Bruce H. Harlton, and others. The sedimentary section is about 25,000 feet thick and the maximum crustal shortening 75 miles (Fig. 3). The example used in the discussion is a sedimentary

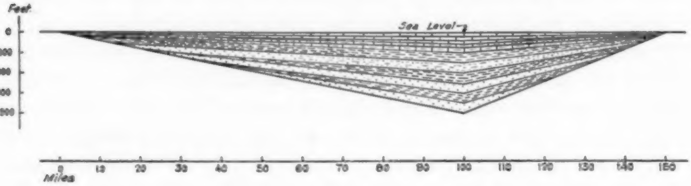

FIG. 3.—Basin 150 miles wide filled with sediments. Maximum total thickness 20,000 feet.

section with maximum thickness of 20,000 feet which was shortened 70 miles.

The deposition of this thickness of sediments has pushed the basin down 4 miles. Crustal shortening and crushing has folded up a mountain range about a mile high; but this is accompanied by an additional

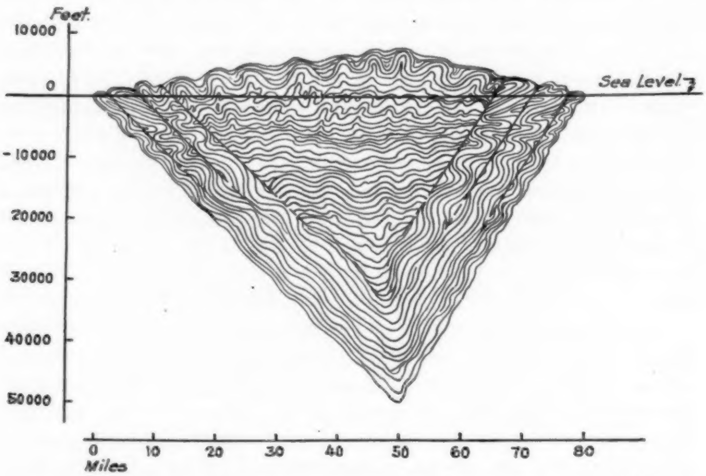

FIG. 4.—Geosynclinal prism shortened 70 miles by crustal collapse. Sediments folded down a total depth of 10 miles and folded up a mile or more. Note that intensity of folding decreases with depth.

downfolding of 6 miles in order to maintain isostatic balance (Fig. 4). The bottom of the original geosyncline is now 10 miles below sea-level. Some additional height, perhaps 1,000 feet or so, should be added as a result of the return to normal of the isogeotherms.

The crushing of the geosyncline of sediments has produced intricate structures such as isoclinal folds, overturned folds, block faults, and great thrust faults.

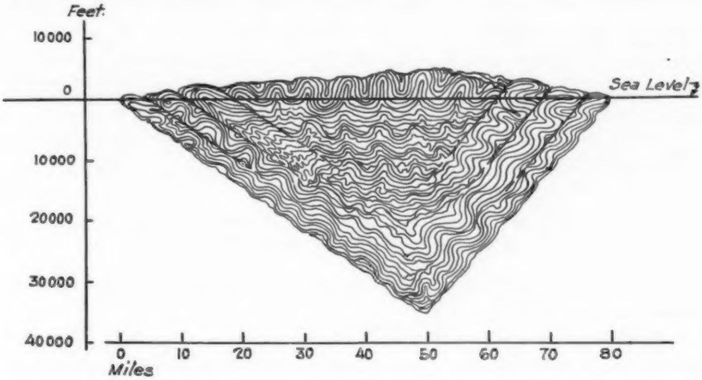

FIG. 5.—Prism has been partly eroded. Isostatic compensation follows erosion. Mountains have been lowered about ½ mile and whole prism has been uplifted about 2 miles. Note that crumpling of lower beds is increased by vertical uplift.

The intensity of the distortion decreases with depth. The lower beds are bent down instead of crumpled. This characteristic is emphasized in the diagram. Faulting may have occurred throughout

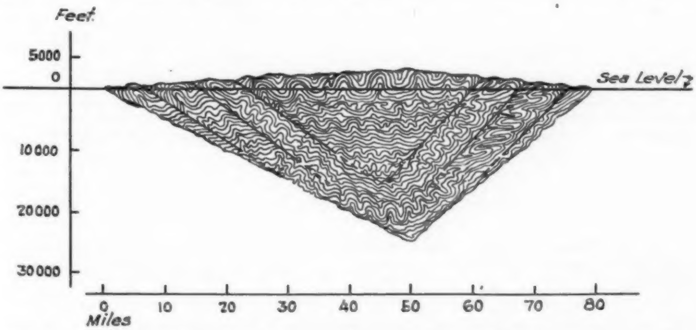

FIG. 6.—Later stage of erosion. Prism now has a maximum thickness of about 5½ miles. Entire mass of sediments is intensely contorted.

the entire zone even though the probable positions of the major thrust faults are the only ones that have been drawn.

The area will be subjected to erosion, the isostatic balance will be upset, and periodic uplifts will occur. Sliding will most probably take place along the thrust fault planes which were originally made

as they are already planes of weakness, but new thrust fault planes also may be formed. The beds below will be crushed and compressed as they are pushed upward because they are being pushed through an area smaller than that of their original extent. Compressive stresses

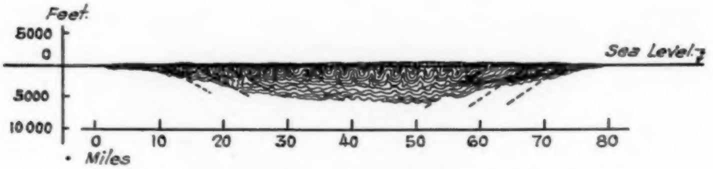

FIG. 7.—Base level has been reached. Total vertical thickness of sediments not much more than 1 mile.

will be dominant during the erosion and vertical uplift stages of this mountain system (Figs. 5 and 6).

Erosion will continue until base level has been reached (Fig. 7). By this time most of the original sediments will have been removed. The remaining section will be composed of intensely contorted and faulted beds, probably highly metamorphosed. Measurement of the

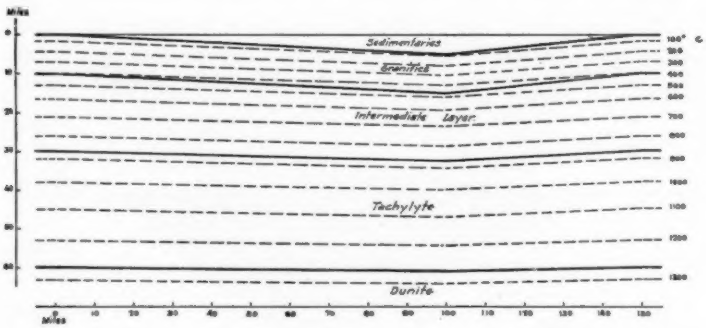

FIG. 8.—Cross section of isostatic layer showing positions of the isogeotherms. Isogeotherms are not bent down as much as are the layers due to partial thermal adjustment.

beds across the outcrops will give a total thickness very nearly equal to the original thickness before folding; yet the vertical dimension of the sediments may be only 6,000 or 7,000 feet.

To note the effect of heat changes it is necessary to look down through the entire isostatic layer. Figure 8 shows the general composition of this section. At the top is a sedimentary wedge 4 miles thick in its deepest part. This is underlain by a 10-mile layer of granitics.

Next below it is the intermediate layer, composed of dioritic to gabbroic crystalline rocks, about 20 miles thick. This rests on the tachylyte layer which is 30 miles thick, and below it is the dunite layer which extends down to great depths, perhaps 1,850 miles. The temperatures shown are those determined by Adams, 400°C. at the base of the granitic layer, 870°C. at the base of the intermediate layer, and 1,270°C. at the base of the tachylyte layer.

When this crustal segment was depressed by the deposition of the sediments the isogeotherms were also depressed. Some temperature adjustment must have taken place during the period of sedimenta-

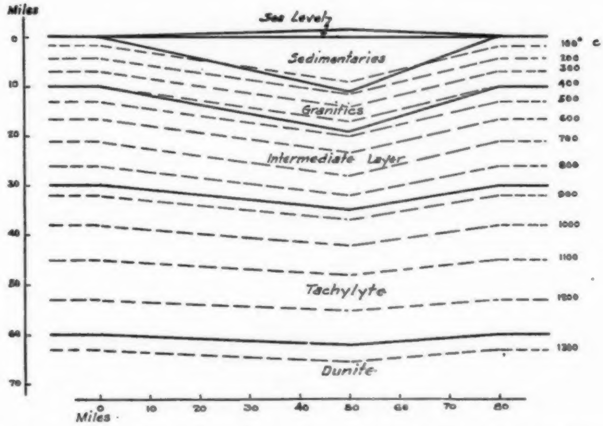

FIG. 9.—Downfolding of the layers due to crustal collapse. Deeper layers are thinned more than upper layers on account of rock flowage. Isogeotherms are bent down less than earth layers since it is assumed that partial thermal adjustment has occurred.

tion; consequently the isogeotherms are not shown to be depressed as much as the earth layers.

The next major change occurs during crustal collapse when the mountains are folded (Fig. 9). The sedimentaries are pushed down to a distance of 10 miles below sea-level and raised a mile or more above sea-level. The other layers are pushed down by similar amounts. The intensity of the downwarping decreases with depth. At depths of 5 miles or more rocks are probably in the zone of flowage. It is, therefore, logical to suppose that some of the compensation during periods of isostatic adjustment may be accomplished by flowage in the isostatic layer as well as in the deeper regions. The figure therefore shows some thinning of the crustal layers, and more thinning in the subcrustal

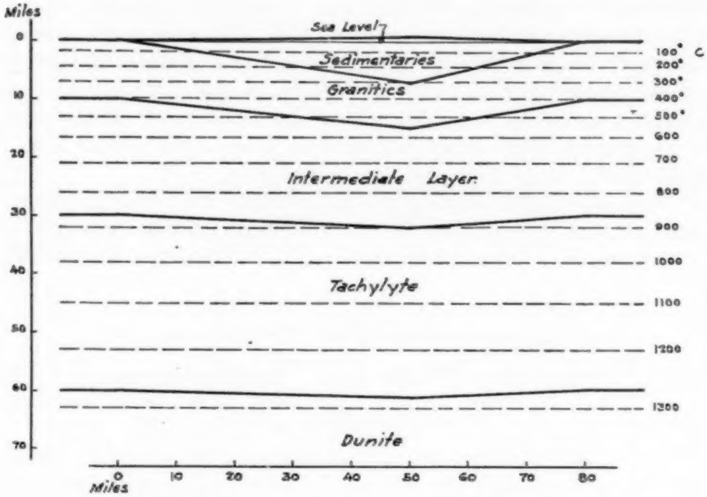

FIG. 10.—The mountain system has been partially eroded and the isogeotherms have returned to normal.

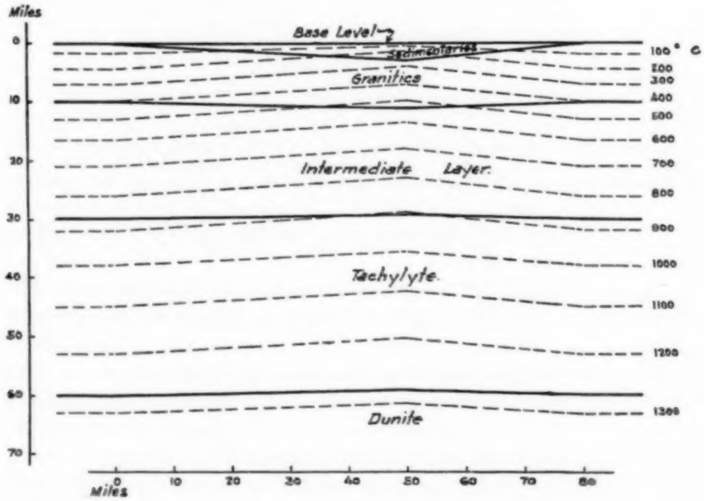

FIG. 11.—The mountain system has been base-leveled and the isogeotherms are turned up.

layers. The isogeotherms are also bent down but not as much as the earth layers.

After a considerable period of erosion has elapsed the isogeotherms will have returned to normal. This is due partly to the conduction of heat through the crust and partly to uplift following erosion (Fig. 10).

As erosion is continued to base level the isogeotherms are turned up. It is assumed that the rate of erosion is greater than the rate of temperature adjustment (Fig. 11). This assumption appears to be correct when the rate of mountain building and denudation is compared with the rate of cooling of the earth since its formation.

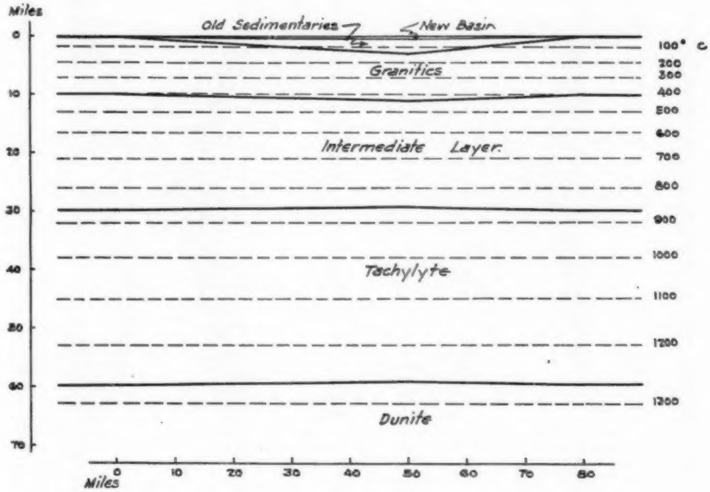

FIG. 12.—The isogeotherms have returned to normal and the resulting shrinkage in the isostatic layer will form a new geosyncline.

After base leveling the area may again become a geosyncline of deposition (Fig. 12). The average amount of temperature abnormality produced by the upbending of the isogeotherms will be 75° to 100°C. throughout the 60-mile layer. As these return to normal the shrinkage of the crust will form a basin about 800 to 1,000 feet deep. This may or may not occur at the time of crustal collapse. This change alone is enough to form a new geosynclinal basin of considerable size.

Temperature changes will produce a geosyncline; but the character of the segment has so changed during the erosion of the mountain range that a new stage of crustal collapse will also cause downwarping. It is an area underlain by heavy rocks and is undoubtedly a segment

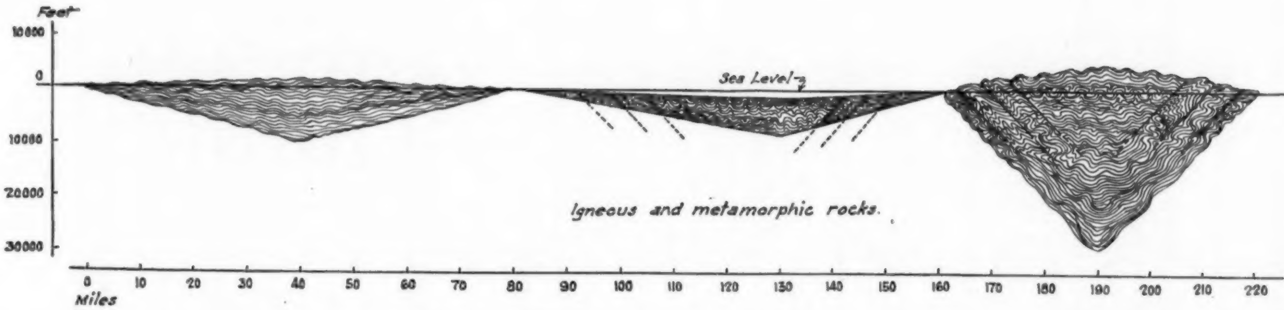

FIG. 13.—Crustal collapse will produce downfolding in the old basin, and mountain systems in the adjacent sedimentary prisms.

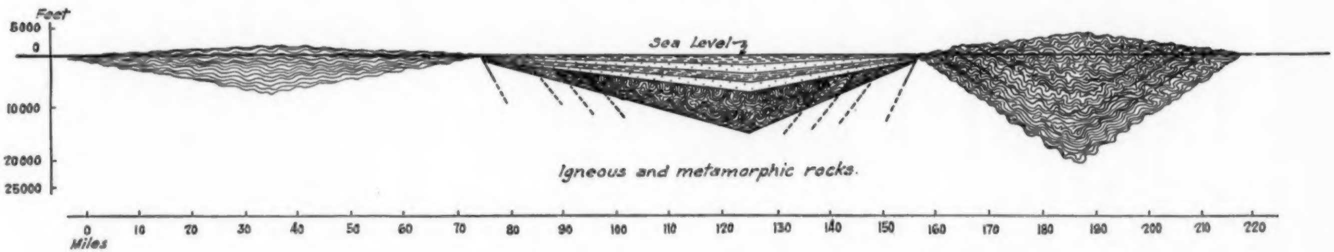

FIG. 14.—The new basin is being filled with sediments and the adjacent highlands are being eroded.

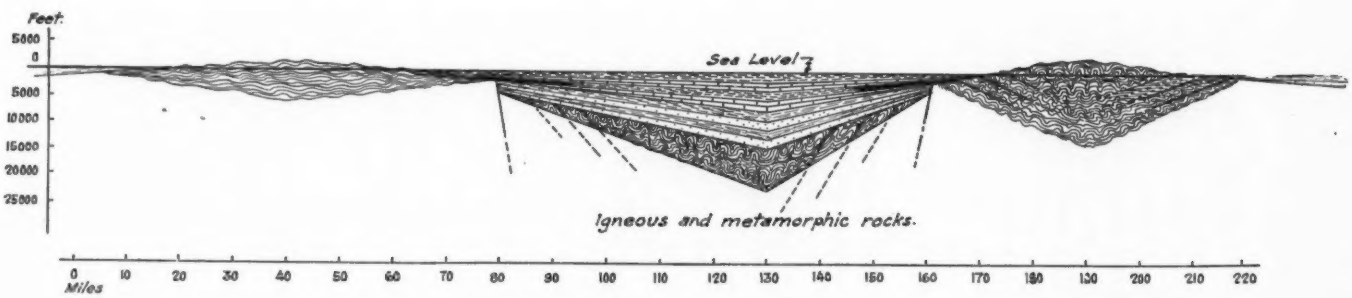

FIG. 15.—Later stage of erosion and deposition.

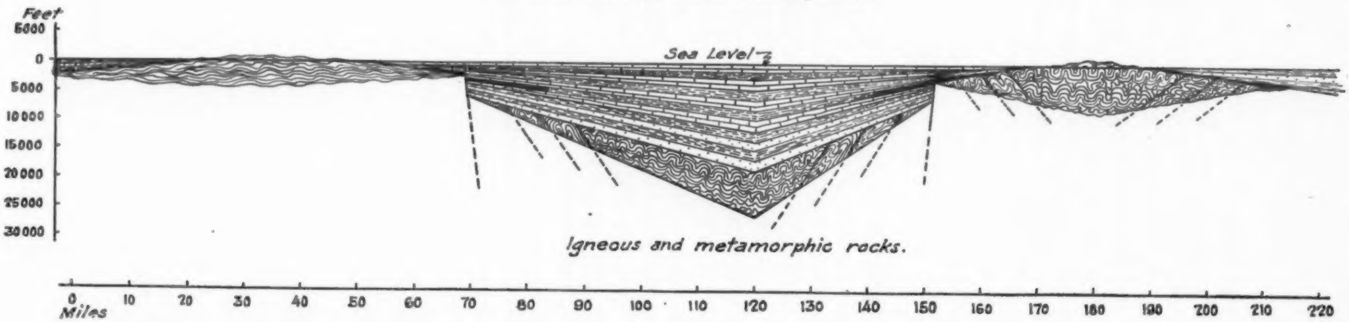

FIG. 16.—Peneplanation of the highland areas with attendant deposition and overlap of sediments.

of strength since the low-density rocks have been eroded and replaced by high-density rocks. Besides, it would be bounded by great sedimentary deposits of low strength which would experience the greatest amount of adjustment and be upfolded. If crustal collapse occurs after the downwarping caused by shrinkage, the segment will have additional advantages. It will have greater density due to cooling, and will be already bent down in the direction of synclinal folding.

In the next stage (Fig. 13) a new geosyncline is formed over the base-leveled sediments of the first mountain system. It is bounded by two folded prisms of sediments which were deposited in the foredeeps formed during the first period of crust collapse. The contact between the old sediments and the new will be a very marked angular unconformity.

The diagrams show the filling of the basin and erosion of mountains in three stages (Fig. 14). The first series of sediments probably are coarse to medium clastics since the surrounding land areas are high. Toward the close of this stage of sedimentation the water is very widespread and shallow. There may be broad swamps in which beds of coal may be deposited. Adjustment will then downfault the syncline as a tremendous block. Most of the faults will dip in toward the basin at angles from 45° to nearly vertical. In the diagrams they are all shown to be nearly 90° because the vertical scale is exaggerated over the horizontal scale. The next series of sediments may be alternating fine clastics and limestones (Fig. 15). They will overlap onto the upward moving blocks. The last stage of filling of the basin will occur at about the time the land areas are approaching base level (Fig. 16). The sediments will be largely limestones and cover an area much wider than the area of the original basin. Much of the land segments will be submerged by overlap.

The original basin which has experienced two complete cycles of deposition is now ready to be compressed and folded again into a mountain system.

THE ORIGIN OF A MAGMA

The first period of base leveling was followed by the formation of a new basin which was developed by reduction to normal of the temperatures in the segment and downfolding during crustal collapse. This is only one of two courses that may be followed. The other course is the formation of a magma.

Removal of some of the overlying load and raising the temperatures may permit crystallization to commence in the tachylyte layer. As the tachylyte is a glass no change of state is required. Its normal

temperatures range between 870° and 1,270°C. At the surface, basaltic lavas can exist in the liquid or semi-liquid state at temperatures even much lower than these. As the glass is already a highly viscous liquid it is only necessary to reduce the viscosity to the point where molecular motion is free enough to permit crystallization. It may not require much increase of temperature or much decrease of pressure, or both, to initiate such action. Very probably a change of only 50°C. and the reduction of pressure by removal of a few miles of rock may permit the first crystals to form.

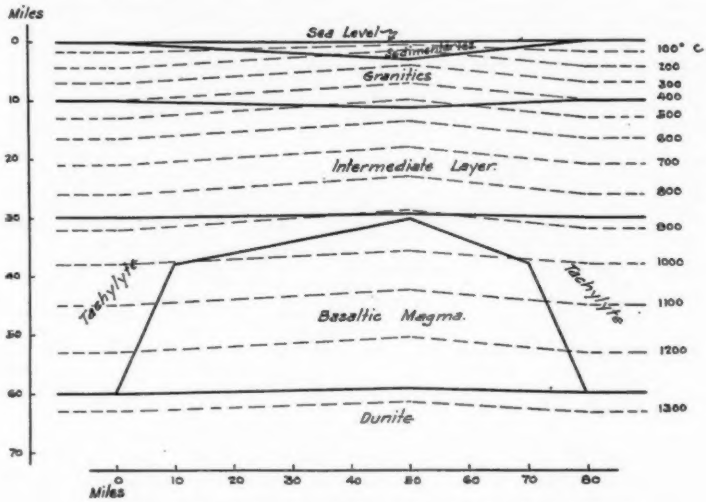

FIG. 17.—Formation of a magma in the tachylyte layer by fractional crystallization.

These first crystals may be exceedingly small, but once crystallization commences the viscosity of the magma will be progressively reduced (Fig. 17). The first crystals will be the least soluble and the most basic. The remaining mass will become enriched in mineralizers and the viscosity is reduced as the percentage of mineralizers is increased. In addition, the rest-magma becomes progressively more and more acidic.

When the viscosity of the magma is sufficiently reduced convection currents will develop (Fig. 18). The temperatures throughout the entire magma will be more nearly equalized and the isogeotherms will be very abruptly upturned. The temperatures may then be out of normal by as much as 400°C.

Radioactive materials are thought to be carried up as vapors in the mineralizers.[25] A low-viscosity magma will permit them to concentrate in the upper zones. They will be a source of heat and when concentrated, may be of considerable importance in maintaining liquidity. The heat of radioactive materials may even increase the temperature of the magma and thus aid in its upward movement.

The magma will work its way upward principally by selective

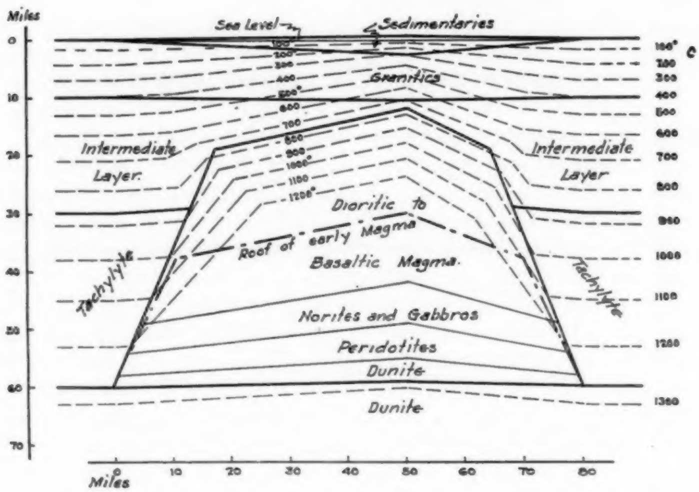

FIG. 18.—Magma is now stirred by convection currents and isogeotherms are quite abnormally turned upward. Magma has already worked its way almost entirely through intermediate layer. Action has been principally by selective fusion.

fusion.[26] The overlying rocks are composed of minerals of different degrees of solubility, and different melting temperatures. The more soluble ones, and they are usually the more acidic ones, will be dissolved out of the overlying rock masses. The rock will thus be disintegrated. Ordinarily, the insoluble minerals are the basic heavier ones and they will sink down through the hot liquid (Fig. 19).

The layers in the lower part of the magma basin will be formed by the collection of the minerals that are crystallized out of the magma with the addition of the insoluble minerals from above. The most basic minerals form first, and progressively less basic minerals are

[25] A. Holmes, *Geol. Mag.* (1915), p. 64.

[26] N. L. Bowen, *op. cit.*

crystallized as the process continues. The lowermost layer will be the most basic and the overlying layers will show a gradation into less basic rocks. For this reason the basal layer will most probably be dunite and it will be overlain in order by peridotites, norites and gabbros, diorites, granodiorites, and granites.

The magma will have a base. The underlying layer is dunite, a monomineralic rock composed of olivine. The magma was formed by

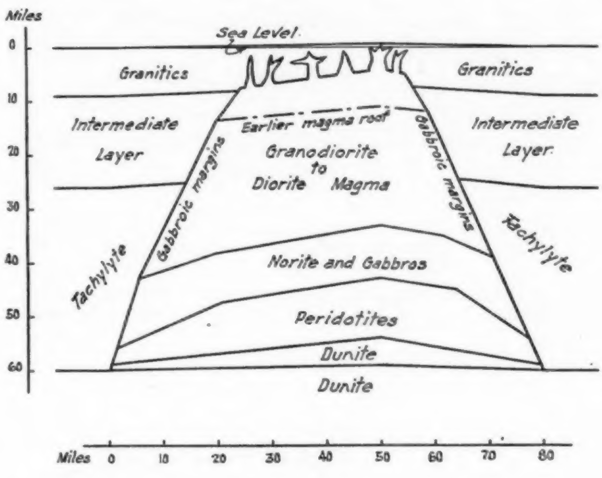

FIG. 19.—Magma has reached granitic layer and zone of fracture. Apophyses reach almost to the surface. Fractional crystallization has by this time developed an acidic magma.

the early crystallization of the mineral olivine. Olivine would be insoluble in the magma and therefore the magma would not be capable of dissolving or melting any of the dunite layer.

The magma will work its way upward through the aid of isostatic adjustment in addition to selective fusion. Heating and expanding will upwarp the segment containing the magma. It is also recognizable that such a segment would be one of very low strength, and readily submissive to compressive stresses. Compression, and uplift, with attendant expansion, may carry on throughout a great part of geologic time. Subsequently, the magma will reach the zone of fracture (Fig. 20).

Once the magma reaches the zone of fracture some of it will be intruded in the form of dikes, sills, laccoliths, and extruded as flows. Repeated intrusions and outbursts will quicken the rate of loss of

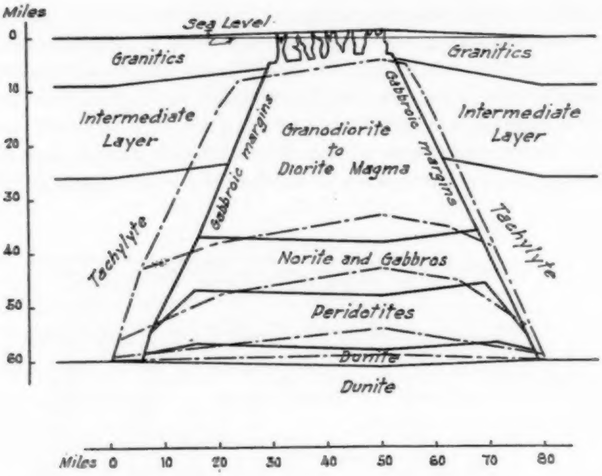

FIG. 20.—Tangential compressive stresses have shortened horizontal cross section of magma resulting in upfolding and downfolding, the latter to maintain isostatic balance.

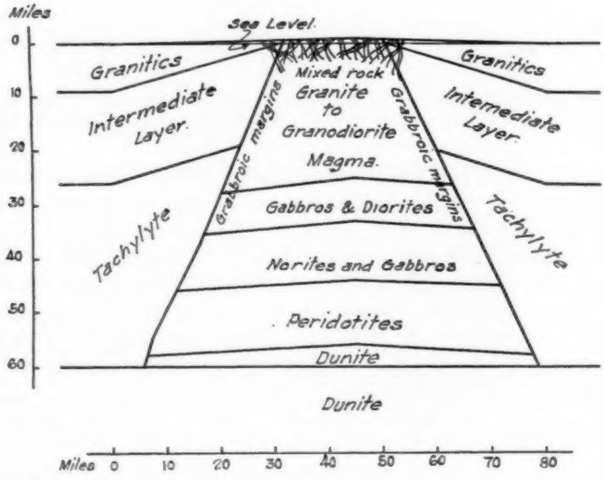

FIG. 21.—Late stage of magmatic activity. Magma is now close to surface. The numerous dikes represent repeated intrusions.

heat and cool the upper portion of the magma. Solidification and shrinkage will follow. The shrinkage may produce an appreciable amount of sinking of the land overlying.

The rate of conductivity will be reduced after the magma has been sealed over and the heat developed by the radioactive elements will be largely retained. The temperature may rise enough to liquefy some of the overlying rock, to work upward by selective fusion or to expand the roof and cause fracturing. This will go on until the magma breaks through. The process of breaking through, sealing over and

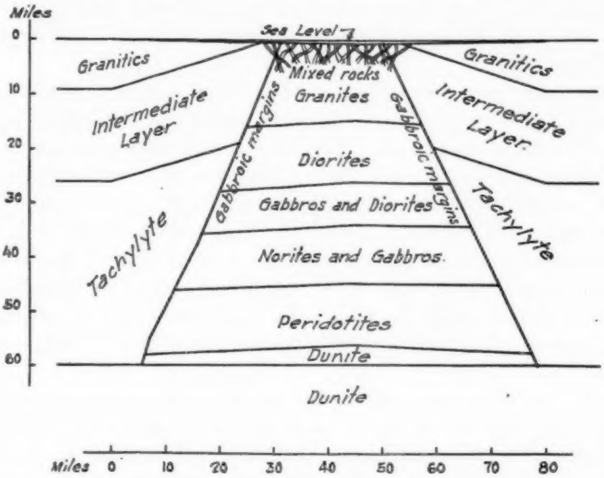

FIG. 22.—Final stage. Magma is completely solidified and cooling, causing shrinking. A new geosyncline is forming.

breaking through again will be repeated until the magma has been finally solidified (Fig. 21).

When the magma is finally crystallized the uppermost part will be cut by innumerable dikes. They represent the repeated intrusions, and will range in composition from basic to extremely acidic.

The side walls of the magma will be gabbroic even to shallow depths. The viscosity in these areas will be high during the entire period of magmatic activity so crystallization will go on with very little fractionation. The margins represent approximately the original composition of the magma.

Finally, the segment will be cooled to normal, and downwarping will result after the area has been base-leveled (Fig. 22). This area will once again become a geosyncline of deposition.

SUMMARY

The motive power which deforms the crust is the shrinking of the earth as a result of cooling. The rigid crust is periodically warped on a mobile interior which is continually being reduced in size. The stresses in the crust are increased until the breaking point is reached. Adjustment by folding and faulting relieve the stresses.

The upfolded areas are reduced by erosion and the downwarped areas are filled by deposition. Isostatic adjustment during these processes causes periodic uplift and depression respectively. A mountain range a mile high will be base-leveled only after the removal of more than 6 miles of rock, and a basin will hold at least six times its depth in sediments.

Two other processes will be at work which will affect the depth of sediments in a basin and the level to which the mountains will be reduced. One is the change in the level of base level and the other is the change in the position of the isogeotherms. The level of the oceans will be raised by displacement. The rock material from the land areas which is deposited in the oceans and epicontinental seas will raise the strand line. The isogeotherms will be turned down during loading of the geosynclines and also during the initial folding of the sediments into a mountain range. As the isogeotherms return to normal expansion of the deformed segment will increase the height of the mountain range.

The rate of folding and erosion will be greater than the rate of thermal adjustment; so by the time base level has been reached the isogeotherms will be turned up. Shrinkage will now be the result of temperature adjustment and a geosyncline will be formed. Crustal collapse will increase the size of the geosyncline and may also fold up mountain ranges in the foredeeps of the original downwarp.

When the first range has been base-leveled and the isogeotherms are upturned, a magma may be formed in the subcrustal tachylyte layer. The rise of temperature and the removal of several miles of rock may reduce the viscosity of the glassy basalt layer by an amount sufficient to permit crystals to form. Once crystallization has been initiated the magma will develop. The rest-magma will become increasingly acidic and the percentage of mineralizers will grow until the liquid body will become mobile enough to be stirred by convection currents. The temperatures in the upper part of the magma then will become more nearly equal to those in the lower part.

The magma will work its way up through the intermediate layer and into the zone of fracture, by selective fusion, and by being com-

pressed horizontally, uplifted, eroded, and uplifted again. When it reaches the zone of fracture it will be intruded and extruded repeatedly until the whole magma body will be finally solidified. The magmatic segment will now undergo a long period of cooling and shrinkage. If much of the shrinkage takes place after base-leveling, a geosyncline will be formed in the same area where the magma had been intruded and where a high mountain range once had stood.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 23, NO. 9 (SEPTEMBER, 1939), PP. 1352-1373, 9 FIGS.

SALEM OIL FIELD, MARION COUNTY, ILLINOIS[1]

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ABSTRACT

The Salem oil field, Marion County, Illinois, was discovered by The Texas Company on July 1, 1938. During the week of January 7, 1939, the field ranked seventh in the United States on the basis of daily production. Twelve months after discovery the field had produced 20,080,000 barrels of oil.

All producing formations of the Salem field are Mississippian in age and include the Benoist sand, the Aux Vases sand, and the McClosky oölitic limestone. At present the Benoist sand is the principal formation being developed.

A geologic study of the Illinois basin indicates early periods of structural adjustment. Marked zones of influence are thought to have been established by these movements. In certain areas of the basin late Mississippian and early Pennsylvanian structural developments have a close relationship to these early established zones.

Subsurface mapping of the Salem field on the Benoist sand and the McClosky oölitic limestone indicates close similarity in structural definition. No increase of structural relief with depth is apparent on the data supplied by present drilling.

The Salem structure covers an area of approximately 14 square miles with a closure of more than 200 feet as mapped on the Benoist sand.

INTRODUCTION

Development of petroleum resources in Illinois may be chronologically divided into three major periods.[3] The original discovery and primary exploitation of commercial production extended over the years of 1882 to 1905. National attention to the state's petroleum possibilities was focused by the La Salle uplift producing areas developed in eastern Illinois during the period of 1905 to 1920. After the year 1920, and prior to the year 1934, exploration was of minor intensity and the total production steadily declined.

Geophysical advancements in exploration methods, as developed in the seismograph, furnished the means of exploring new territory in Illinois. Extensive seismic exploration entered the state in 1934. Leasing and subsequent production of petroleum from newly found structural areas followed the exploration program and during the year 1938 Illinois again became a major producing state. The Salem field is an outstanding example of this latest period of production.

OBJECT OF REPORT

This report covers particularly the stratigraphy and geologic structural conditions associated with the Salem oil field of Marion

[1] Read before the association at Oklahoma City, March 24, 1939. Manuscript received, June 1, 1939.

[2] Division geologist, The Texas Company.

[3] J. Marvin Weller and Alfred H. Bell, "Illinois Basin," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 21, No. 6 (June, 1937), p. 782.

County, Illinois. It also includes a discussion of the regional structural setting of the field. Producing formations important to the field are described. A résumé of data concerning present production of oil and estimations of reserves are included. Production methods being advanced in the field, as well as pipe-line facilities for transportation of the crude petroleum, are of direct interest and, therefore, a part of this report.

It is desired that the report may present an example of the geological, production, and reserve factors representative of the present activity of the petroleum industry in Illinois.

ACKNOWLEDGMENTS

The Illinois Geological Survey is distinguished by the complete coöperation extended through its personnel to the geologists and petroleum operators active in the state. Reports of the Survey have been freely used for geologic data included in the report and this fact is gratefully acknowledged. A. H. Bell, of the Survey's Petroleum Division, and L. E. Workman, of the Survey's Stratigraphic Section, have been of much assistance to the writer in geologic work necessary to the completion of this report.

The writer is indebted to B. M. Miller, V. C. Scott, L. H. Lukert, and W. S. Johns, of The Texas Company geological personnel, for their very valuable contributions and criticisms covering geologic data. J. F. Blackwell and E. F. Dell, of The Texas Company engineering personnel, and the scouting department of the company assisted materially in the production data and plate assembly.

The permission of The Texas Company to publish the report and associated geologic data from their files is sincerely appreciated.

LOCATION AND REVIEW OF AREA

The Salem oil field is in Ts. 1 and 2 N., R. 2 E., Marion County, in the central southern region of Illinois (Fig. 1).

Subsurface structural development of the field area was defined through seismograph exploration of The Texas Company. The discovery well was located 760 feet east of the west line and 660 feet south of the north line of the NW. ¼ of Sec. 5, T. 1 N., R. 2 E. This test, designated as the E. Tate No. 1, was drilled to a total depth of 1,918 feet where it was in the Ste. Genevieve formation. Commercial showings of oil were encountered and cored in the Benoist sand and the Aux Vases sand. The test was completed as a commercial producer on July 1, 1938. Initial production, representing oil from both the Aux Vases and Benoist sands, was 732 barrels in 23 hours, with 175,000

FIG. 1.—Distribution of producing areas, Illinois.

cubic feet of gas. On August 26, 1938, the Aux Vases sand was plugged and the well produced through a choke from the Benoist sand alone.

Following the discovery of oil in the Salem field, drilling operations rapidly assumed major proportions and in January, 1939,[4] the field ranked seventh in the United States on the basis of daily production.

STRATIGRAPHY

SURFACE STRATIGRAPHY

The uppermost bedrock strata in central Illinois are Pennsylvanian in age. Considerable erosion has taken place on this surface and the region was covered during the Pleistocene period by a thick mantle of glacial material. In the Salem area this mantle ranges from 40 to 60 feet in thickness and effectively masks topmost Pennsylvanian beds of the McLeansboro series. The drainage pattern has in a few places penetrated the glacial material at Salem but sufficient outcrops are not available for surface mapping of bedrock structure.

SUBSURFACE STRATIGRAPHY

The stratigraphic sequence represented in the subsurface of the field is shown by the lithologic log of drill cuttings of the discovery well (Fig. 2).

The section portrayed by this log indicates approximately 1,100 feet of Pennsylvanian sediments represented by the McLeansboro, Carbondale, and Pottsville series. These series consist of alternating shales, sandstones, and several thin limestones and coals. By far the largest percentage of the Pennsylvanian beds are medium-grained, slightly micaceous sandstones and dark gray shales. The Herrin, or No. 6 coal, is encountered at approximately 700 feet in the Salem area and is a consistent marker bed.

The Menard limestone presents the first distinctive Mississippian marker of the area. This limestone is a part of the Menard formation of upper Chester age and is encountered at approximately 1,200 feet. At the close of the Mississippian period the borders of the Illinois basin were raised and greatly affected by erosion. Due to this condition the Upper Mississippian beds penetrated in the Salem area may range somewhat higher in the section than the Menard formation.

An average thickness of 680 feet of the Chester series is drilled at Salem. A rather full depositional range was furnished for the development of the Cypress, Benoist and Aux Vases formations. The series

[4] "Illinois and Kentucky," *Oil and Gas Jour.*, Vol. 37, No. 34 (January 5, 1939). Staff article on field operations.

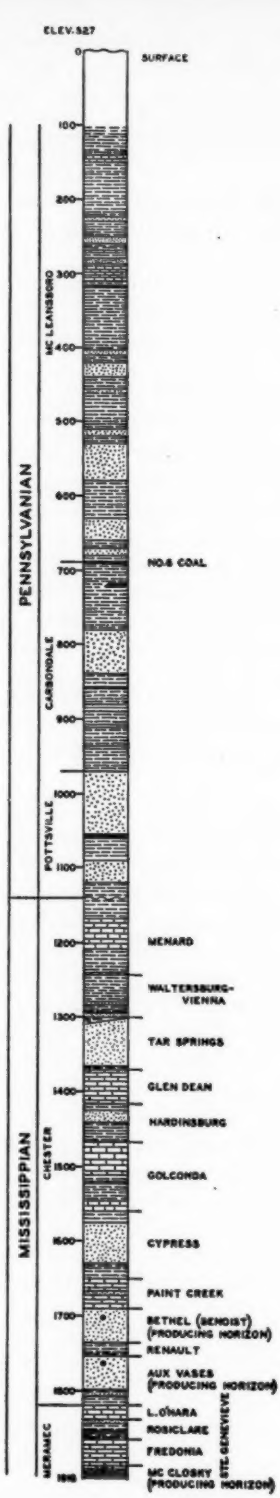

FIG. 2.—Stratigraphic section of discovery well, Salem field.

consists of gray, green, and variegated shales, medium-coarse to fine-grained sandstones, and gray to tan lithographic to coarsely crystalline limestones.

The top of the Meramec group (Mississippian age) is reached in the Salem field at depths ranging from 1,820 to 2,045 feet. The top formational member of this group is the Ste. Genevieve limestone. Subdivisions of the Ste. Genevieve limestone are, in descending order, the lower O'Hara, the Rosiclare, and the Fredonia. The term "McClosky" is used in this report as representing an oölitic, porous condition of the Fredonia.

The St. Louis limestone formation (Meramec group) ranges from 120 to 145 feet below the top of the Ste. Genevieve limestone. Although present drilling depths in the Salem field have not penetrated below the St. Louis limestone, it is expected that a normal sequence of the southern Illinois stratigraphic section will be encountered. The Devonian is estimated at a depth of 3,350 feet and the St. Peter sandstone at 5,000 feet in the field.

REGIONAL STRUCTURAL GEOLOGY

During a long period of geologic history the present Illinois basin was the northern component of a much more extensive regional basin area extending down the Mississippi Valley.[5] Movements occurring in post-Pennsylvanian time formed a barrier across southern Illinois and isolated the present basin after the rocks which now occupy it had been formed.

Regional structural influences originating from the Cincinnati arch on the east dating from Middle Ordovician time have a direct bearing on the structure of at least the eastern basin area.

On the western side of the basin the Ozark uplift with original definition in pre-Cambrian time has been a decided factor in determining the structural history of the basin through subsequent movements.

Devonian movement and associated faulting on the extreme east flank of the Ozark uplift bordering western Illinois have been described by Weller.[6] Fault differentials as great as 1,000 feet have been observed. It seems logical to assume that Devonian movements materially influenced the western flank of the Illinois basin.

Structural movements in the Illinois basin prior to the general

[5] J. M. Weller, "Oil Possibilities of the Illinois Basin," *Illinois Geol. Survey Rept. Investig. 27* (1936), p. 4.

[6] Stuart Weller, "Geology of Ste. Genevieve County, Missouri," *Missouri Bur. Geol. and Mines*, Vol. XXII, 2nd Ser. (1928), p. 299.

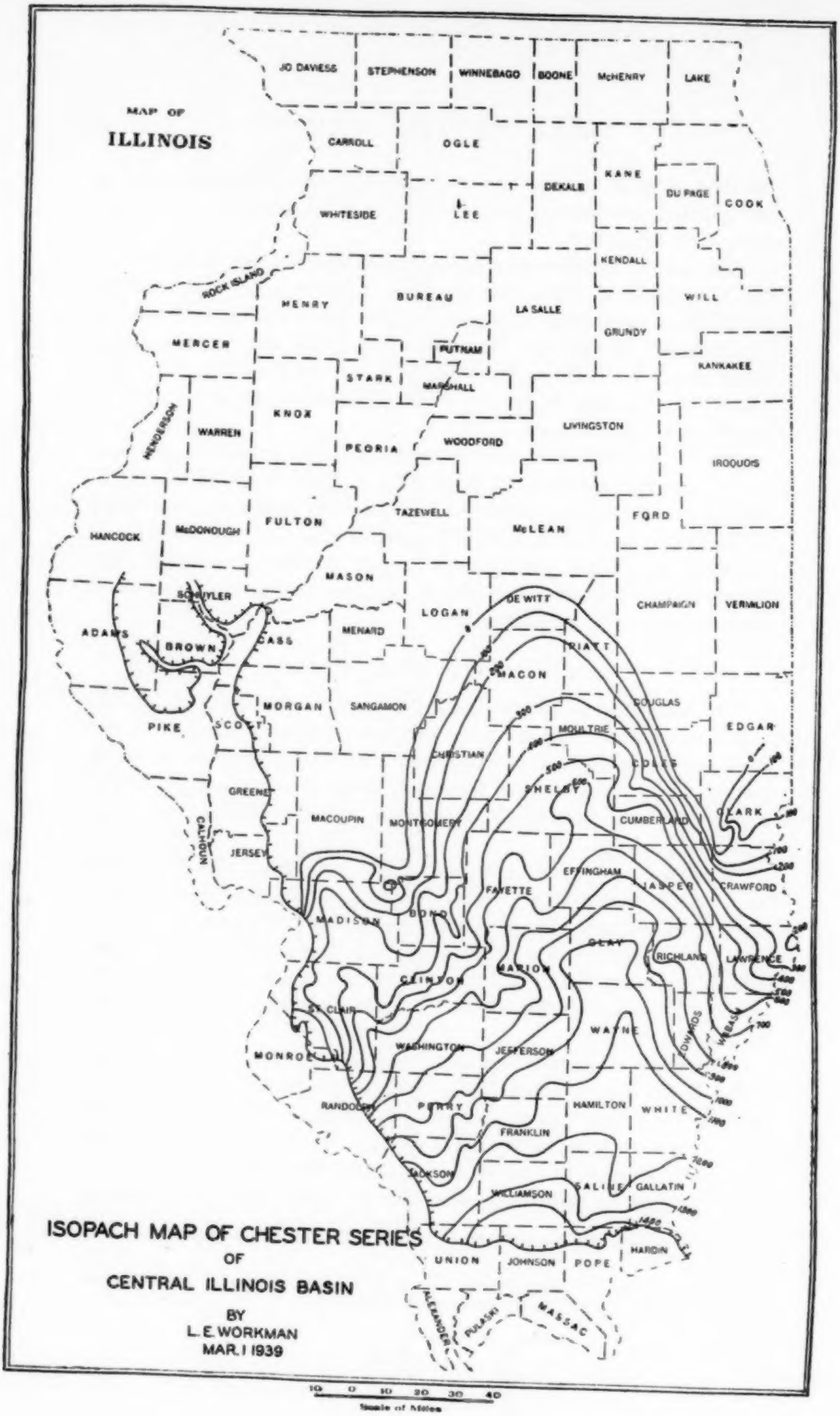

FIG. 3.—Chester isopach map of central Illinois basin.

folding of the late Mississippian and early Pennsylvanian periods are of decided importance to the correct interpretation of its history even though definite evidence is seriously lacking for conclusive study in much of the area.

Mylius[7] indicates, from a study of structure prior to Pennsylvanian time in Illinois, that post-Lower Mississippian folding took place along a series of parallel axes trending east of north in the Bellair-Champaign area of Douglas and Coles counties, Illinois.

Recently completed isopach mapping of the Chester series in the central Illinois basin by L. E. Workman of the Illinois Geological Survey is presented in Figure 3.

Although regional areas of thinning indicated in the Chester series may be attributed to post-Mississippian structural movement and erosion yet certain of these areas are strongly suggestive of earlier structural influences. Two particular localities of the map are presented in this regard.

Through the area of Crawford, Jasper, and Richland counties of eastern Illinois the Chester isopach mapping indicates a pronounced regional nosing of the contours toward the southwest. It is suggested that structural movements may have occurred along deep-seated lines of weakness in this area during early periods. The direction of regional nosing shown by Chester isopach mapping is closely similar to the direction of early structural axes studied by Mylius in the Champaign-Bellair area on the north.

The second locality which is indicated particularly by the Chester isopach mapping is found in Montgomery and Bond counties, and is designated the Carlinville-Centralia zone of structural influence. This area also indicates possible early lines of movement toward the southeast. Detailed studies on the east flank of the Ozark area by Weller, and the Devonian movements, described by him in Ste. Genevieve County, Missouri, as cited, seem closely related to similar movements which may have taken place on this western flank of the Illinois basin. Deeper drilling in the vicinity is necessary for conclusive evidence.

Sufficient data are not available at this time to satisfactorily determine the importance of the Duquoin flexure in Perry and Franklin counties, Illinois, with respect to early regional structural influence in the basin. It is desired to suggest, however, that this area very possibly experienced early movements in a northeasterly direction which were directly associated with the Ozark influences. The steep

[7] L. A. Mylius, "Oil and Gas Development and Possibilities in East Central Illinois," *Illinois Geol. Survey Bull.* 54 (1927), p. 28.

FIG. 4.—Important zones of regional structural influence, Illinois basin.

west dip of the Salem field structure, discussed later in this paper, suggests deep-seated lines of basement weakness, or faulting in the lower formations. The axes of these lines are closely related regionally to the Duquoin zone of influence as directed northeastward.

The principal areas of structural movement in the oil-producing region of southern Illinois are shown on Figure 4.

The pattern presented indicates several very interesting regional associations with producing areas. The southwestward influence from the area of Crawford, Jasper, and Richland counties is directed toward the later post-Mississippian or early Pennsylvanian structural trends developed through the producing areas of Clay, Richland, and Wayne counties. The Carlinville-Centralia influence is directly reflected in the later folding forming the Centralia and Sandoval producing structures. The Centralia structure particularly has a northwest-southeast alignment indicative of this early relationship. The Dix, Salem, and Louden structural areas are presented as possibly associated with the early lines of movements originating from the Duquoin deformation.

A possibility that is immediately presented in connection with the regional structural geology is cross-folding produced by possible intersection of the Carlinville-Centralia and Duquoin zones of movement. This is not indicated by the structural features defined thus far in the area and the condition is thought rather remote principally through the rapid loss of definition eastward of early movements originating from the Carlinville-Centralia area. The structural pattern, governing the areas now defined, which appears most plausible to the writer, is supplied by Cheney[8] as follows: "*en échelon* folding and faulting may be the natural result of the local features along an older line of weakness being accentuated by potent forces coming from a new direction." Lines of weakness in the basement complex very likely were evidenced by early movements followed by subsequent movement both through direct structural influence and accentuation caused by basin subsidence in Illinois. All these factors are directly related to the present regional subsurface pattern of the Basin area.

GEOLOGIC STRUCTURE OF SALEM FIELD

The subsurface structure of the Salem field as mapped on the top of the Benoist sand (Chester series) is shown on Figure 5.

The area for which structure contours are shown covers approximately 14 square miles. The crest of the structure is located generally in Sec. 5, T. 1 N., R. 2 E., and Secs. 31 and 32, T. 2 N., R. 2 E. The

[8] M. G. Cheney, "History of the Carboniferous Sediments of the Mid-Continent Oil Fields," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 6 (June, 1929), p. 588.

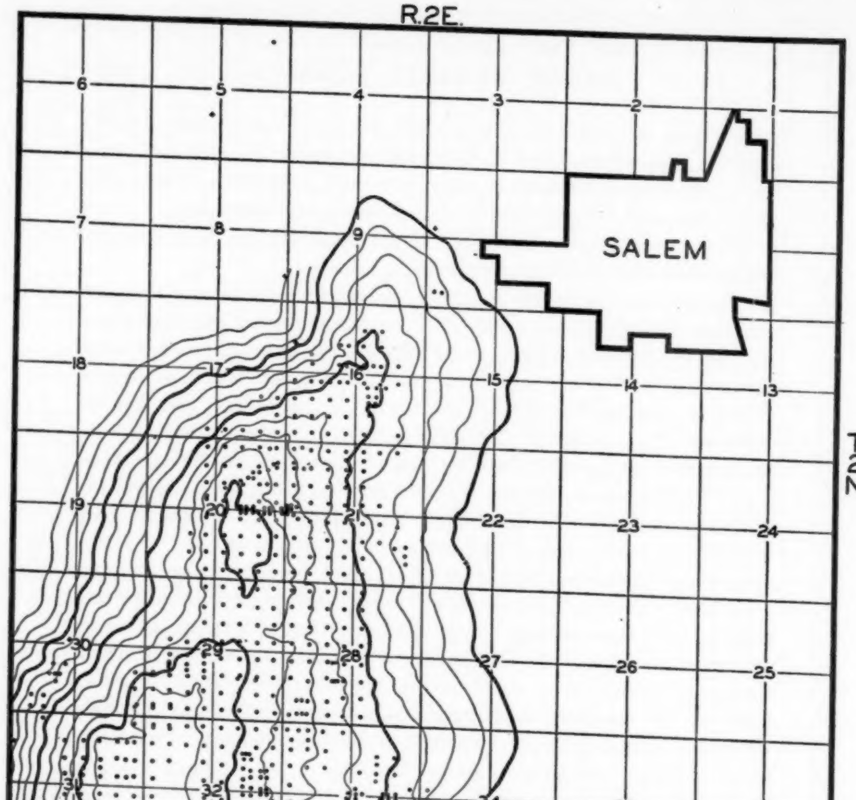

FIG. 5.—Subsurface geologic structure, Salem field, contoured on top of Benoist sand.

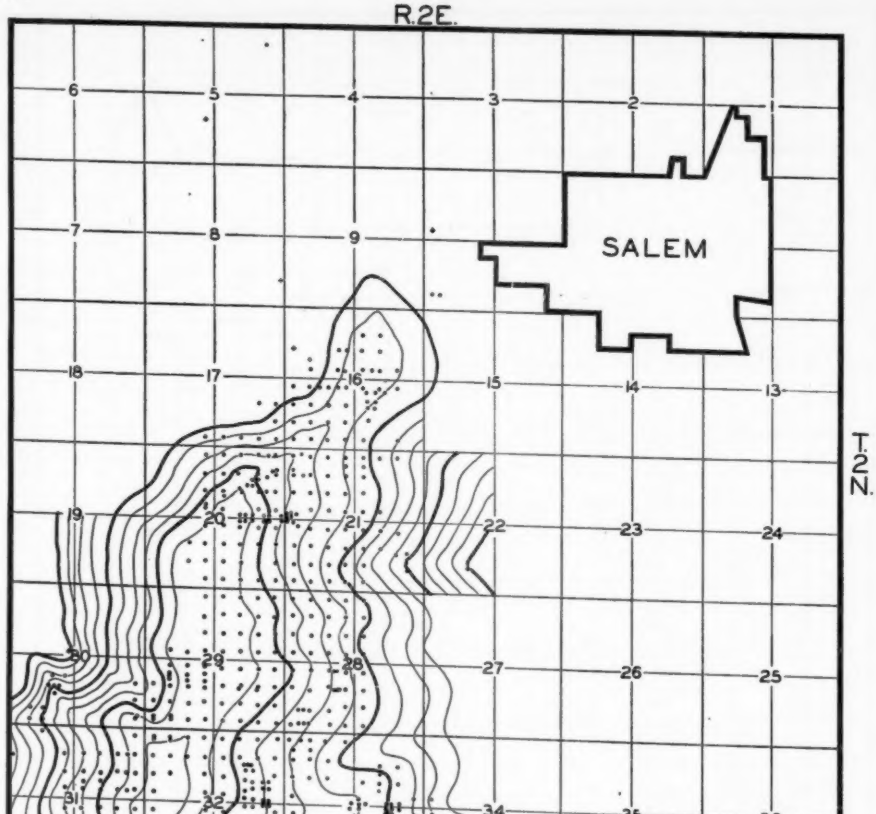

FIG. 6.—Subsurface geologic structure, Salem field, contoured on top of McClosky zone.

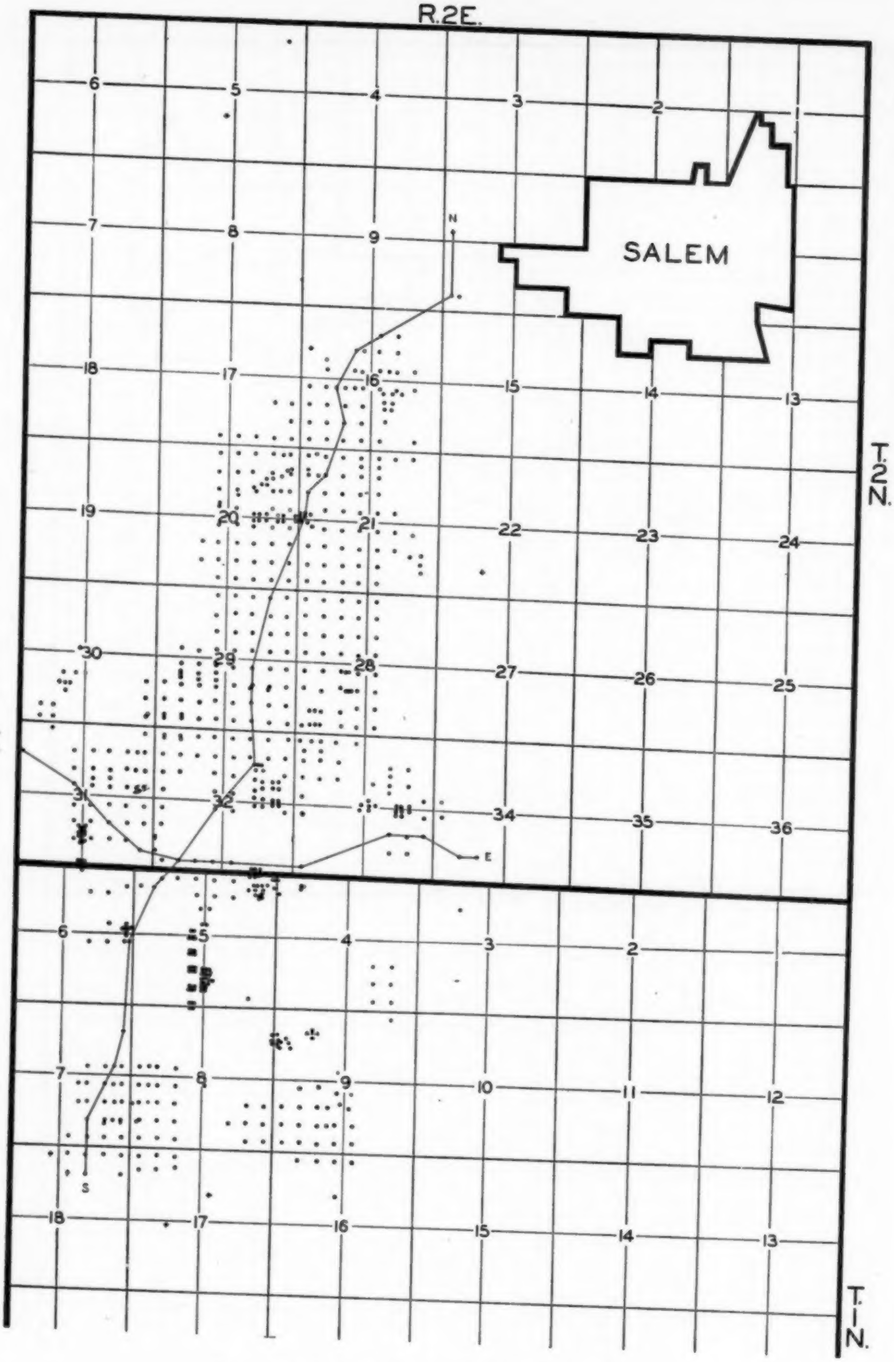

FIG. 7.—Location of cross section lines, Salem field.

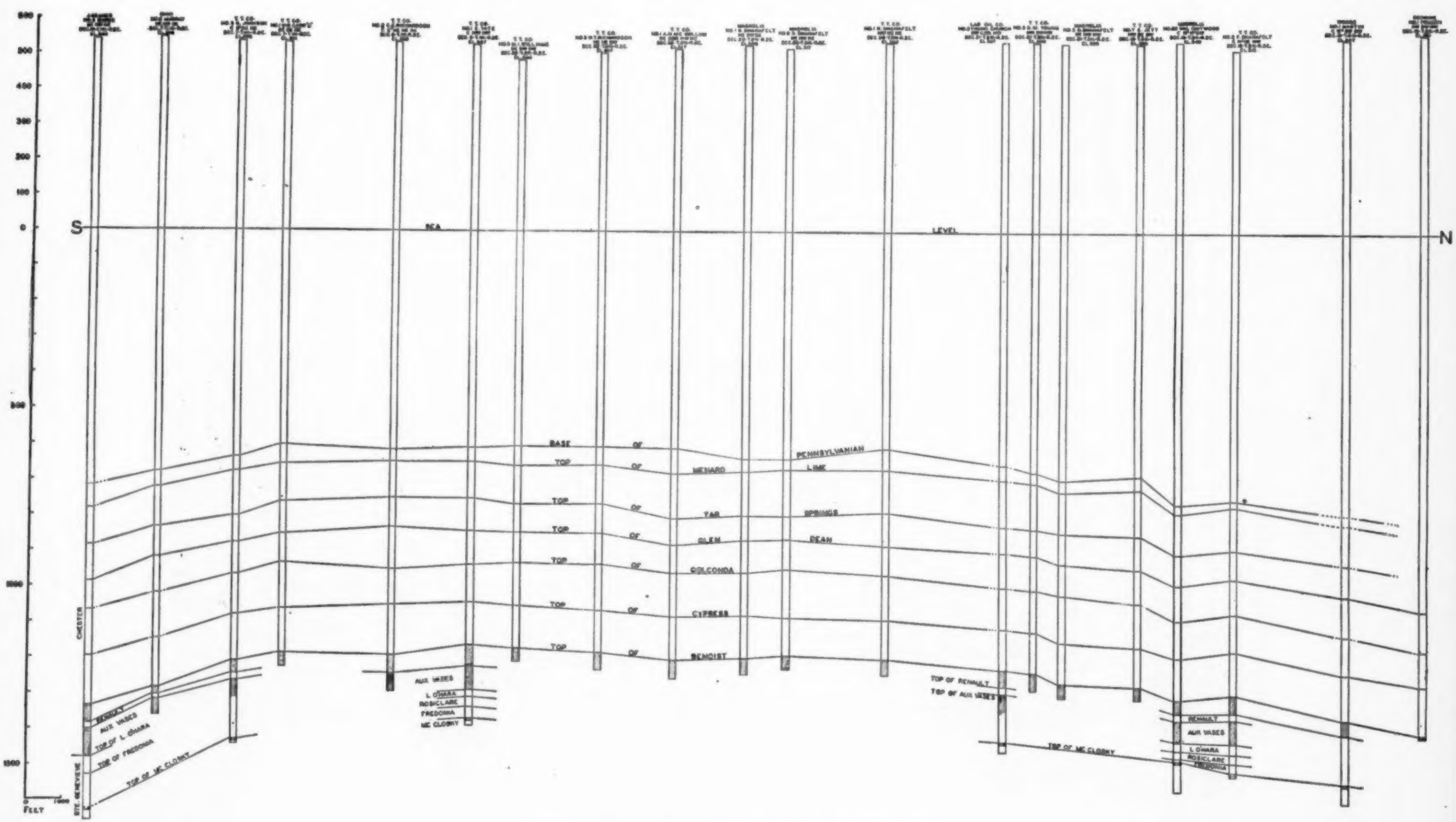

Fig. 8.—South-north geologic cross section of Salem field.

direction of axial trend is slightly northeast. The closure mapped on the top of the Benoist sand is more than 200 feet.

The Salem structure as reflected by the Benoist sand has rather mild dip components on the northeast and also on the eastward or basinward side. The average east dip is 85–90 feet to the mile. The

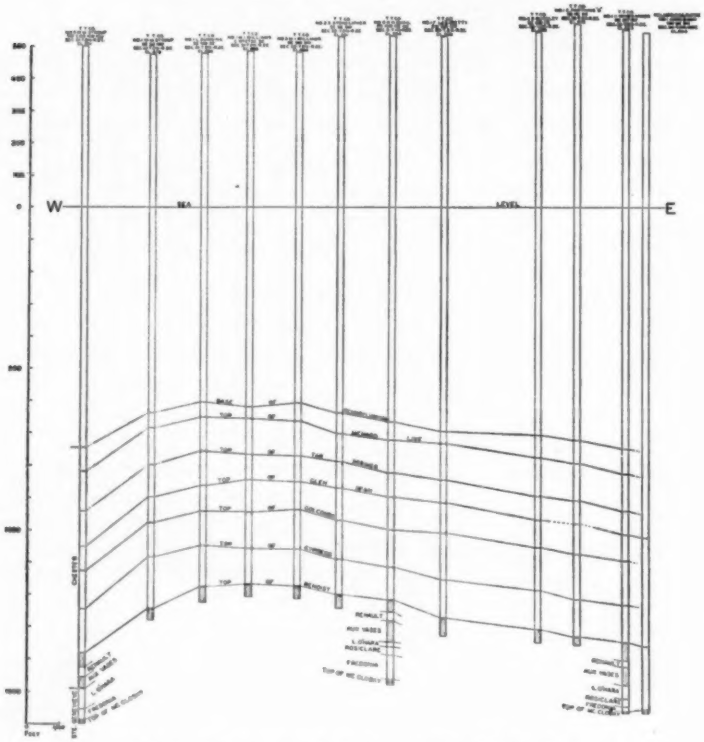

FIG. 9.—West-east geologic cross section of Salem field.

south, southwest, and west dip components are distinctly more pronounced. The average westward dip per mile is 220 feet. Although no faulting is evidenced in the Pennsylvanian or Mississippian beds to the present depth explored in the Meramec group, the strong west dip of the structure is suggestive of possible faulting in lower formations along old lines of weakness in the basement complex.

Figure 6 illustrates the subsurface geologic structure on the Mc-

Closky zone (Ste. Genevieve formation). Due to limited drilling to this zone to date the subsurface control for mapping is much more remote than that on the Benoist sand. The subsurface structure indicated by the McClosky map is similar to that of the Benoist map. No apparent increase in dip is evident. The average east dip on the McClosky is 80 feet to the mile and the average west dip is 220 feet to the mile.

Because of the small interval (200–250 feet) between the Benoist sand and the McClosky no information is gained as to possible increase of structural accentuation with depth in this area. Deeper drilling may provide information on this possibility.

The location of east-west and north-south lines of cross sections of the Salem structure is shown in Figure 7. The lines were located with the object of presenting typical cross sections of the structural area. Some variation in the directional attitude of the sections was necessary to secure the greatest advantages from the examination of well cuttings available and data supplied by electrical logs.

Figures 8 and 9 represent the geologic cross sections of the Salem oil-field structure.

The asymmetrical character of the Salem fold is clearly represented. Particular attention is directed to the disconformable contact of the Pennsylvanian and Mississippian strata. This disconformity is encountered either at the base of the thick Pottsville sand zone or in the shales directly below where it may be recognized by a lithologic change from dark, exceptionally micaceous shale of the Pennsylvanian section to light green, non-micaceous shale of the Menard formation (Chester).

The Menard limestone furnishes an excellent marker for defining the amount of Mississippian erosion present over the structural area. The local portion of the Illinois basin in which the Salem structure is situated appears to have experienced peneplanation of Chester formations down to the Menard with subsequent covering by early Pennsylvanian beds. The local erosion shown by the cross sections at the disconformity indicates that the area had negligible structural relief, other than regional position on the western basin flank, at the close of Mississippian time. No consistent thinning is apparent over the structural area in the Chester. The cross sections indicate that the major structural development at Salem must have occurred during Pennsylvanian time.

The cross sections indicate the accentuated west dip which is probably related to deep-seated lines of weakness. The interval from the Glen Dean limestone to the Ste. Genevieve limestone is less in

the Salem field than like intervals studied farther eastward. This fact may indicate some early structural movement at Salem possibly related to late Devonian or early Mississippian origin. The erosional character of the top of the Ste. Genevieve limestone may be also cited in this regard.

PRODUCING ZONES

At present the Mississippian section includes all the formations productive in the Salem field. Formations of the Chester series and Meramec group are the productive zones of the field. Petroleum has not been encountered in the Pennsylvanian strata. Deep zones below those drilled are prospective for production. Among these may be mentioned particularly the Lower Mississippian formations, the Silurian-Devonian interval, and the Ordovician. West of the Salem field commercial oil and gas are encountered in producing areas on the west flank area of the Illinois basin from each of the formations enumerated.

The Benoist sand of the Chester series is the major producing formation of the Salem field to date. This sand is correlated with the Bethel formation and is equivalent to the Tracy which is productive on the La Salle anticline in Lawrence County. The Benoist sand at Salem is encountered at an average depth of 1,725 feet. The sand averages 45 feet in thickness and is described as greenish to gray, fine- to medium coarse-grained angular sand. Muscovite flakes are present throughout the sand body. The top of the sand is slightly silty with only fair porosity; however, very good porosity is encountered immediately below the top portion of the sand body and continues to the base.

The Benoist sand has marked regularity of deposition and porosity in most of the field area. A few wells on the southwestern and south flanks of the structure have shown an absence of sand. The sand section absent is replaced by shales of the Paint Creek formation. Offset tests to wells reporting an absence of Benoist have drilled practically a normal section of the sand, indicating decided local depositional or erosional phases. To the writer's knowledge the southwest and south flanks of the Salem field are the only areas showing these conditions on present exploration.

Oil and gas are encountered throughout the Benoist sand section. Water level in the field has been tentatively established on the sand at a subsurface position of 1,350 feet below sea-level. The most prolific production from the Benoist sand is directly related to struc-

tural position. Slight changes indicating porosity and permeability variables are evident.

The Aux Vases formation of the basal Chester series is reached on drilling in the Salem field at an average depth of 1,800 feet. This is the second productive zone with respect to stratigraphic position in the field. The Aux Vases formation consists principally of sand and averages 55 feet thick. The sand is gray, fine to sub-medium in grain size. Porosity is rather variable due to silty streaks in the sand body and variation in degree of cementation. Muscovite flakes are common and the sand in part is somewhat similar to the upper part of the Benoist.

In preliminary estimates as to the comparative productivity of the various producing zones in the Salem field, the Aux Vases formation was considered of rather questionable importance due to its variable porosity and purity of sand body. Additional data now available through the greater number of tests penetrating the Aux Vases have indicated much greater regularity of deposition and absence of foreign material. Production possibilities now indicated from the Aux Vases are very encouraging.

The Ste. Genevieve formation is encountered in the Salem field at an average drilling depth of 1,950 feet. Due to erosional characteristics in the top members of the formation the average penetration necessary to reach the McClosky varies considerably. A general approximation of the penetration necessary ranges from 25 to 40 feet.

The McClosky is possibly the most widely known petroleum formation in Illinois production history. It is a typical limestone reservoir in that wells equally well located structurally may be dry though offsetting producing locations. This condition is caused entirely by porosity factors controlling accumulation.

A typical McClosky description from the Salem field indicates the top portion composed of calcareous oölites approximately $\frac{1}{2}$–1 millimeter in diameter. The central McClosky interval is very porous with a small amount of calcareous cementing material. The remainder of the zone is composed of tan to gray limestone, subcrystalline and fossiliferous, very oölitic with some calcite filling of pore spaces.

Excellent conditions of regular porosity development and saturation of the McClosky are indicated in most of the Salem field. The McClosky "pay" averages 15 feet in thickness in the field area. Although McClosky tests are not numerous at the present stage of drilling development, it is indicated that few producing areas in Illinois will exceed this field in regularity of porosity development.

DISCUSSION OF CYPRESS FORMATION

In view of its large oil production in many fields in southern Illinois, a geologic presentation of the productive zones in the Salem field would not be complete without mention of the Cypress formation. This formation, consisting principally of a well developed sand body in the field area, contains salt water, and no commercial oil showings are evidenced. The Cypress is separated stratigraphically from the Benoist sand by the Paint Creek formation which consists mainly of limestone and shale.

The Louden field in T. 8 N., R. 3 E., approximately 30 miles north and slightly east of the Salem area, produces most of its oil from the Cypress formation. The Benoist sand is productive at Louden as at Salem. These two producing areas are generally considered to be of the same age of structural development and are indicated along the same alignment of structural trending.

Certain hypotheses may be presented to explain this variation in the production prospects of the Cypress formation between the two fields mentioned: (1) local structural development outside accumulation limits; (2) lensing or porosity barriers within the Cypress formation; (3) different periods of structural development; and (4) accumulation, migration, or non-migration theories concerning petroleum.

The writer believes that the first condition presents the most logical approach to solution. Chester sediments in the Illinois basin very likely had, in the main, a southern source from ancient land masses associated with Appalachia. The depositional uniformity, as related to thickness and porosity of the Cypress formation, appears to exceed the comparative uniformity of the Benoist sand in the western portion of the southern Illinois basin. The Louden field occupies a position in closer proximity to the westward Chester limits of the Illinois basin than the Salem field. The average sand thicknesses of the Cypress and Benoist at Louden are 44 feet and 15 feet, respectively, as compared with thicknesses of 55 feet and 45 feet at Salem. These comparative thicknesses are suggestive of a rapid approach to a littoral zone of the Benoist sand while fairly normal regularity of Cypress deposition appears to continue farther westward. Migration of oil updip from the central basin area could thus reach farther westward limits in the Cypress sand than might be possible in the Benoist. The Salem and Louden areas, receiving their structure-forming movement principally in late Mississippian or early Pennsylvanian, were subject to the migration conditions prevailing in the Cypress and Benoist sands at those times. Accumulation in both areas was possible

from the Benoist sand due to its westward restriction of migration. In the case of the Cypress sand, however, migration had passed westward from the Salem area but still included the Louden structure within the limits of accumulation due to its position nearer the western boundary of the Chester basin.

The Louden area shows considerable sand variation in the Cypress formation in local areas but to assign a general lensing characteristic as the cause for the absence of oil in the formation at Salem seems untenable due to the regularity of the sand in the Salem field. Porosity factors and sand composition appear quite comparable in both pools.

Different periods of structural development are not indicated by present geologic evidence in the fields. It is granted that the productivity of the Cypress at Louden and the absence of oil in the same formation at Salem may be explained by migration, non-migration, or accumulation theories.

PRODUCTION DATA OF SALEM FIELD

Tables I and II include information assembled with reference to production in the Salem field. The averages shown were obtained on the basis of present production data available.

TABLE I

Producing Formation	*Average Thickness (Feet)*	*Average Initial Production (Barrels)*	*Average Bottom-Hole Pressure (Pounds)*	*Producing Wells (Feb. 1, 1939)*
Benoist sand	45	600	650	519
Aux Vases sand	55	200	707	16
McClosky zone	15	1,130	735	64

Note.—On July 1, 1939, the Salem field had 1,033 producing wells.

TABLE II

Producing Formation	*Average Porosity (Percentage)*	*Average Permeability (Millidarcys)*
Benoist sand	17.5	228
Aux Vases sand	16.1	154
McClosky zone	10.3	429

It is not possible at this time to determine an accurate gauge of the present potential daily production possibilities of the Salem field because a number of the producing wells are choked. Pipe-line deliveries are at times prorated and a considerable amount of the oil produced by independent operators is trucked to local refineries. No general proration or spacing agreements are in effect in the field. Accurate production totals from specific formations are not obtainable due to the general practice of producing wells from different formations into common tankage and unrecorded movements of oil by truck.

The average daily production for which figures are obtainable was 133,643 barrels per day during June, 1939. The total production to July 1, 1939, for the entire pool was 20,080,000 barrels. This figure covers a 12-month interval dating from the discovery of July 1, 1938. The gravity of the crude petroleum ranges from 38° to 41°Bé. and is marketed under the present, posted price average of $1.05 per barrel (July, 1939).

PETROLEUM RESERVE DATA

Table III, showing the reserve estimate of the Salem field is taken directly from the report published by the Illinois-Indiana Petroleum Association.[9]

TABLE III

SALEM FIELD RESERVE ESTIMATE

Producing Formation	*Thickness (Feet)*	*Area (Acres)*	*Recovery Per Acre Foot (Barrels)*	*Recovery Per Acre (Barrels)*	*Total (Barrels)*
Benoist sand	40	10,000	200	8,000	80,000,000
Aux Vases sand	35	8,000	100	3,500	28,000,000
McClosky zone	10	10,000	300	3,000	30,000,000
Total					138,000,000

Close spacing of offset wells in certain parts of the field has been required of the operators because of the existence of numerous small tracts of land, for example, private roadways, school lots, church lots, and cemeteries.

Because of the diversity of ownership of these small tracts, the desire of some operators to produce their wells wide open and the absence of any State authority for controlling production, plans for repressuring and maintaining reservoir pressures have been nullified. As a consequence, a substantial amount of the oil in the Salem structure that would have been produced with the aid of efficient repressuring, has been irretrievably lost.

PRODUCTION METHODS AND PIPE LINES

Drilling development in the Salem pool has been almost entirely done by rotary drilling methods. The units in current use are all of the lighter-type equipment using motor power. Fuel is gas, gasoline, butane, or fuel oil (Diesel). The average size of hole drilled is $8\frac{3}{4}$–9-inch to the producing zone. Cores are taken of the producing formation and casing set at the top, or in some instances of production from two zones the pipe is set through and perforated opposite the upper

[9] *Illinois-Indiana Petroleum Association Report* (December, 1938).

production. Casing size in common use is 7-inch outside diameter. The casing is usually cemented to the top of the hole in the best production practices. Derrick heights vary from 87 to 96 feet.

A large number of the wells drilled in the pool flow naturally. In instances where pumping equipment is necessary, light, portable motor units are installed using either gas, gasoline, or electricity for power generation.

Drilling time in the Salem field averages 10 days from time of spudding to completion of Benoist sand wells. In the case of McClosky tests, 14 days are required for completion. The usual procedure is to set casing on the top of the producing zone. Benoist tests are usually completed with cable tools while McClosky tests are completed by rotary methods through coring.

There are four pipe lines serving the Salem pool (Table IV).

TABLE IV

Company	*Size of Line*		*Daily Capacity (Barrels)*	*Destination*
	Diameter (Inches)	*Length (Miles)*		
Central States Pipe Line Co.	8 10	35 38	25,000	Lawrenceville, Ill.
Central States Pipe Line Co.	4	9	10,000	To Illinois pipe line, Sandoval, Ill.
Manley Pipe Line Co.	4	13	6 to 8,000	Centralia, Ill.
Magnolia Pipe Line Co.	4	9	10,000	To Illinois pipe line, Sandoval, Ill.

Missouri and Illinois R.R. 6 loading racks located in Secs. 20 and 21, T. 2 N., R. 2 E., and in Sec. 25, T. 2 N., R. 1 E.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 23, NO. 9 (SEPTEMBER, 1939), PP. 1374-1392, 7 FIGS.

CORRELATION OF MINABLE COALS OF ILLINOIS, INDIANA, AND WESTERN KENTUCKY[1]

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ABSTRACT

The numbers by which the principal coals of Illinois, Indiana, and western Kentucky are commonly known are a result of independent work by the geological surveys of these three states and for the most part do not correspond. Certain interstate correlations have been made during the last 75 or more years and much attention has been directed toward the correlation of coals within the individual states but no attempt has previously been made to effect a comprehensive correlation of the coals of the Eastern Interior basin as a whole.

Of the 50-odd seams present 13 are mined, 6 in Illinois, 5 in western Kentucky, and 8 in Indiana. The most important coal is Harrisburg No. 5 of Illinois (=Kentucky No. 9=Indiana V). The Herrin coal No. 6 of Illinois (=Kentucky No. 11) is second in importance. Less important widespread seams are Rock Island coal No. 1 of Illinois (=Minshall of Indiana) with which is tentatively correlated Murphysboro coal "No. 2" of Illinois (=Mannington of Kentucky), Colchester coal No. 2 of Illinois, and Danville coal No. 7 of Illinois (=Indiana VII). Coals important only in restricted areas are lower and upper Brazil blocks of Indiana, Coals III, IV, and VI of Indiana, Grape Creek coal of Illinois, and coals No. 12 and 14 of Kentucky.

INTRODUCTION

The political boundaries which separate the states of Illinois, Indiana, and Kentucky divide the great Eastern Interior coal basin into three unequal parts. Although the strata, including the coal beds, pass without interruption from one state into another, each part possesses its own individual system of nomenclature, long ago adopted and still in general use.

KENTUCKY NOMENCLATURE

The first generalized section of the Coal Measures in the Eastern Interior basin was worked out in western Kentucky and was published by D. D. Owen in 1857.[4] In this section the coals were numbered from the base upward from 1 to 18. The numbers 9 to 12 have been widely and generally correctly applied throughout western Kentucky and this part of the section includes the most important commercial coals of the area. Numbers used by later workers for higher seams are commonly of only local significance and Owen's numbers 1 to 8 have

[1] Published by permission of the chief, Illinois State Geological Survey. Manuscript received, June, 1939.

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[4] D. D. Owen, *Third Report of the Geological Survey of Kentucky* (1857), pp. 18-24.

not generally been employed outside of his typical area in Union County. His No. 5 coal is now known as No. 6 and his No. 6 as No. 7.

ILLINOIS NOMENCLATURE

A. H. Worthen, with the aid of Leo Lesquereux who had assisted Owen in Kentucky, attempted to apply the Kentucky numbers in Illinois but unsatisfactory results caused him to abandon this system and develop a system of his own based mainly on the outcrops in the Illinois valley. His stratigraphic section in which the coals were numbered from 1 to 8 was published in 1868[5] and these numbers were later applied with varying success throughout the state. Worthen's coals 2 and 3 are the same bed and were mistakenly separated because of different roof conditions. Several of the coals in southern Illinois were miscorrelated by Worthen and it is only very recently that data necessitating revision of his correlation of these beds have been obtained.

INDIANA NOMENCLATURE

Lesquereux introduced the numbering system of the western Kentucky coals into Indiana but he was not followed by other geologists. E. T. Cox lettered the seams from the base upwards and this system was used in the Indiana reports for many years. In G. H. Ashley's report of 1899[6] successive Roman numerals were assigned to the more important seams and intermediate thinner coals were designated by adding a letter to the number of the next lower important seam. This system has persisted in Indiana to the present.

Ashley's original standard section was based on observations in Vigo and Clay counties but because of the early recognition of some of the intricate and confusing miscorrelations of his report a supplement was published in the thirty-third annual report of 1908 in which these were partially corrected and the section in Sullivan and Greene counties was adopted as standard.

STATE BOUNDARIES

The development of three different systems of nomenclature for the coals of the Eastern Interior basin has resulted from the working out of the stratigraphic succession of the beds by State agencies in its three political subdivisions with little or no regard for each other's work. A state line is not a natural boundary between areas of different

[5] A. H. Worthen, *Geol. Survey of Illinois Vol. 3* (1868), pp. 5, 6.

[6] G. H. Ashley, *Indiana Department of Geology and Natural Resources Annual Report 23* (1899), pp. 89–91.

geologic development and it may be much easier to correlate beds from one state into adjacent parts of another than it is to correlate these same beds between certain areas within a single state. For example, the relations of the coal beds of the Danville district of Illinois to the Indiana coal fields are much clearer than are their relations to the coals in any other part of Illinois, and the coals of southern Illinois are much more easily correlated with those of western Kentucky than with those of western Illinois.

CORRELATION OF COALS

Where outcrops, mine workings, or bore holes are abundant and closely spaced it may be possible actually to trace a single coal seam for long distances and thus establish the identity of coals at more or less widely separated localities. Where such information is unavailable, however, or where a seam decreases below workable thickness or entirely disappears other means of recognition must be employed. Those which have been generally relied upon include the character of the coal, the nature of floor and roof, the position and type of partings, the kinds of fossils included in associated beds, and the intervals below or above conspicuous coals or other types of strata such as limestones or thick sandstones. The fact that none of these criteria, singly or in combination, is infallible is amply demonstrated by the numerous miscorrelations that have been made. With increasing distance between the areas correlated the reliability of these criteria rapidly decreases.

SEDIMENTARY CYCLES

The recognition by members of the Illinois State Geological Survey that the different types of strata which make up the Coal Measures in the Eastern Interior basin normally occur in sequence with certain definite relations to each other has served to furnish a new means of coal correlation (Fig. 1). These sequences occur in cyclic repetition[7] and each cyclothem (strata formed during an individual cycle of sedimentation) may be traced and correlated as a unit regardless of the variations of its constituent members. Thus it is possible to trace for long distances the horizon of a coal, even though the coal be entirely absent, and to recognize it as the same seam if it again be developed in some other area.

[7] J. M. Weller, "Cyclical Sedimentation of the Pennsylvanian Period and Its Significance," *Jour. Geology*, Vol. 38 (1930), pp. 97–135.
H. R. Wanless and J. M. Weller, "Correlation and Extent of Pennsylvanian Cyclothems," *Bull. Geol. Soc. America*, Vol. 43 (1932), pp. 1003–16.

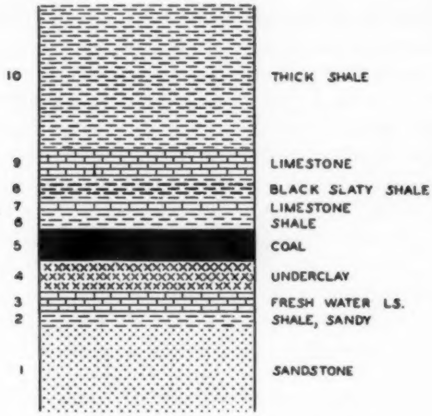

FIG. 1.—Diagram showing succession of members in ideally developed cyclothem. In actual occurrence all members are discontinuous and where present may vary greatly in thickness, and most of them show different lithological characters from place to place. With very rare exceptions cyclothems are incomplete and lack one or several of these members. Basal sandstone (No. 1) locally rests unconformably on lower beds and in some places occupies channels cut beneath horizons of other coals. Fresh-water limestone (No. 3) is lacking in many cyclothems. Underclay (No. 4) is commonly more extensive than associated coal although some coals occur without underclay. Shale and marine limestone (Nos. 6 and 7) are erratically developed and rarely occur associated with workable coals. Black slaty shale, marine limestone, and upper shale (Nos. 8, 9 and 10) are commonly more persistent and more uniform lithologically than most other members.

VARIATIONS IN SECTION

The succession of Coal Measures strata is very different in the northwestern and southeastern parts of the Eastern Interior basin. The sediments were apparently derived from a mountainous area on the southeast and in the southeastern part of the basin the geological section is much thicker and more sandy than it is on the northwest. But most important of all, the southeastern section consists of a greater number of cyclothems than are present farther northwest. The additional cyclothems of the southeastern section more or less gradually lose their identity northwestward, pass into almost unrecognizable rudiments that may be present here and there, or disappear entirely. This situation introduces the greatest difficulty that is encountered in cyclothemic correlation and some of the problems so raised have not yet been satisfactorily solved.

SOUTHERN VERSUS WESTERN ILLINOIS

The Coal Measures succession is greatly reduced both in thickness and in number of members present throughout a large area in western

Illinois near East St. Louis and on the north. Many of the beds below coal No. 6 are entirely absent or are only discontinuously developed in this area and the intervals separating several coals or their horizons are very small. Also there is extremely pronounced thickening, within short distances, of the section east of the Duquoin anticline, which extends north and south in the southern part of the basin near the third principal meridian, and this is accompanied by the introduction of a number of new cyclothems. As a result of these conditions the well known sections of southern and western Illinois are very different and correlation is unusually difficult because in the intervening area of much thinned section where some of the cyclothems are very similar and discontinuous it is possible unwittingly to jump from one coal or its horizon to another only a few feet above or below.

STATUS OF COAL CORRELATIONS

A state-wide investigation of the Coal Measures stratigraphy of Illinois by the Illinois State Geological Survey has been in progress for more than ten years and is rapidly nearing completion. During the course of these studies, as time and opportunity have permitted, numerous observations have been made in Indiana and western Kentucky in order to obtain data bearing upon stratigraphic problems encountered in Illinois. In addition grants from the National Research Council to J. M. Weller in 1930 and from the Geological Society of America to H. R. Wanless in 1935 and 1936 have helped to finance observations outside of Illinois that would not otherwise have been possible.

At the present time the principal unsolved problems of correlation within the Eastern Interior basin concern the highest and lowest parts of the Coal Measures. The correlations of the principal minable coals are for the most part clear and any uncertainties which still exist are indicated in the following discussions.

COALS OF EASTERN INTERIOR BASIN

Some fifty or more different coal seams are present in the Eastern Interior basin. Most of them are thin and no single seam is everywhere developed. Almost every one of these coals, however, thickens in one or more areas so that it becomes locally important and has been dug at least on a small scale for local fuel requirements. Some of the thinner coals, where favorably situated, particularly in Indiana, have been stripped on a fairly large scale and stripping operations will doubtless be extended on such beds in the near future. Most of these seams can be excluded from the present consideration, however,

and attention mainly concentrated on those beds which do at present, or have in the past, supported large-scale underground mining activity.

MINABLE COALS

In Illinois six coals are of minable thickness and quality, in Indiana there are eight, in western Kentucky five. Listed in a single sequence from the bottom up these are as follows: (1) lower Brazil Block coal, Indiana; (2) upper Brazil Block coal, Indiana; (3) Rock Island No. 1 coal, Illinois; (4) Staunton Coal III, Indiana; (5) Colchester No. 2 coal, Illinois; (6) Linton Block Coal IV, Indiana; (7) Springfield No. 5 coal, Illinois; (8) Grape Creek coal, Illinois; (9) Coal VI, Indiana; (10) Herrin No. 6 coal, Illinois; (11) Coal No. 12, Kentucky; (12) Danville No. 7 coal, Illinois; (13) Coal No. 14, Kentucky. The following table shows the principal correlations and the general areas of importance of these coals.

Northern and Western Illinois	*Southern and Eastern Illinois*	*Western Kentucky*	*Indiana*
		Coal No. 14	
Coal No. 7	Danville No. 7		Coal VII
		Coal No. 12	
Coal No. 6	Herrin No. 6	Coal No. 11	
			Coal VI
	Grape Creek		
Springfield No. 5?	Harrisburg No. 5	Coal No. 9	Petersberg V
			Linton Block IV
Colchester No. 2			
			Staunton III
Rock Island No. 1	Murphysboro No. 2	Mannington	Minshall
			U. Brazil Block
			L. Brazil Block

COLUMNAR SECTIONS

The accompanying graphic columnar sections (Figs. 3–6) show on a uniform scale the relations of all the coals present in different parts of Illinois, Indiana, and western Kentucky between the top of the conglomeratic Caseyville (Mansfield, Makanda, Babylon) sandstone and the higher marine Lonsdale (Cutler, Madisonville, West Franklin, Somerville) limestone. The more important limestones and sandstones are shown in their proper positions and recognizable coal horizons without coal are indicated by dashed lines. The important minable coals are correlated from column to column and are briefly discussed later. Figure 2 shows the geographic locations of the columnar sections.

Columns 1 to 4 (Fig. 3) show the development of the most important part of the Coal Measures in the northwestern part of the Eastern

Interior basin where a number of cyclothems present to the southeast are absent or represented by only sporadically occurring rudiments. The cyclothems from coal No. 2 upward, which constitute the principal parts of these sections, are persistent throughout this area and are recognizable in southern Illinois.

1. *Northern Illinois.*—The Coal Measures succession of La Salle County and vicinity differs considerably from the sections present in all other parts of the Eastern Interior basin but careful study has

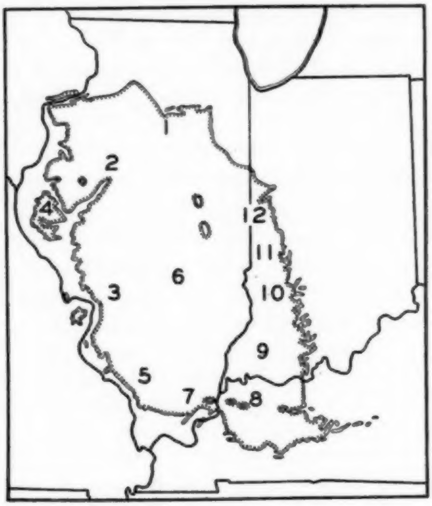

FIG. 2.—Outline map showing extent of Coal Measures in Eastern Interior basin, and locations of graphic columnar sections presented on Figures 3–6. Width of area mapped, approximately 375 miles.

served to identify most of the beds with the more characteristic development of this part of the section in the Illinois valley.

Three coals have been mined in this district. The first is coal No. 7, the second is believed to be coal No. 6, and the third is coal No. 2. The "2nd vein" is lenticular and occurs at varying distances below the Brereton limestone which is a thin but fairly persistent bed. Thin coals, which are at least approximately equivalent to Coal IV of Indiana and the Grape Creek seam of eastern Illinois, are present above coal No. 2 and above the horizon of coal No. 5 but elsewhere in the northwestern part of the basin they are very rarely and only locally developed. Along the La Salle anticline the strata below coal

No. 2 are represented by thick fireclay similar and equivalent to the Cheltenham clay of the St. Louis district.

2. *Illinois valley*.—The Coal Measures section has been worked out in greater detail along the Illinois valley and vicinity than any-

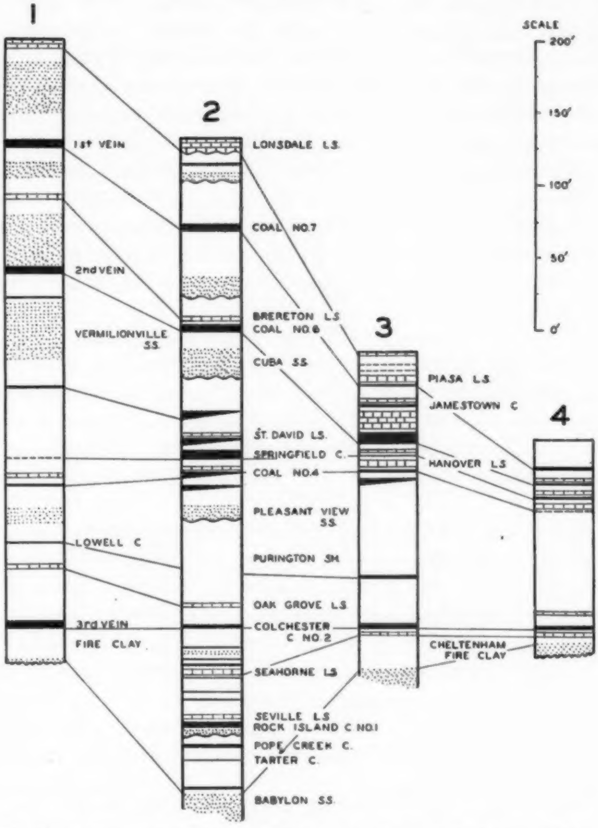

FIG. 3.—Columnar sections 1–4. Vertical scale shown in feet, here and in Figures 4, 5, and 6.

where else in the Eastern Interior basin. It consists of a well developed succession of cyclothems that have been identified in almost all parts of the basin and many of the most useful stratigraphic key beds are present here.

Coal No. 5 is the principal seam mined in this part of Illinois

although coal No. 1 was formerly important near Rock Island and coal No. 2 has been extensively worked in small local mines. In a few very restricted areas other coals achieve respectable thicknesses but are too limited to be of appreciable importance.

3. *Madison and Macoupin counties, Illinois.*—The entire Coal Measures thins progressively down the Illinois valley toward St. Louis. Below coal No. 2 the section passes into the thick Cheltenham fireclay except for the basal Babylon sandstone and the Seahorne limestone which extends for some distance as a persistent bed, then gradually becomes discontinuous and finally disappears. Above coal No. 2 the sandstones become thinner and wedge out, and most of the shales decrease in thickness. Only coal No. 6 is workable. Several of the limestones, however, reach their maximum development here and the thin Jamestown coal makes its appearance, becomes more notable farther southeast, and finally becomes workable in parts of western Kentucky.

4. *Western Illinois.*—The thinnest development of the Coal Measures in the Eastern Interior basin occurs in Adams and Brown counties of western Illinois. Many members have disappeared entirely from the section and only the Purington shale and coal No. 2 are present with unreduced thicknesses. The section here does not continue quite high enough to reach the Lonsdale limestone or its horizon.

Columns 5 to 8 (Figs. 4 and 5) show the development of the middle part of the Coal Measures in central and southern Illinois and western Kentucky. The stratigraphic section has thickened so greatly in part of this area, as the result of the greater development of sandstones and the introduction of new members, that it has been necessary to divide these columns into upper and lower parts at Illinois No. 2 coal and these are presented separately on Figures 4 and 5, respectively. Correlations with Figure 3 are indicated by the introduction of western Illinois names and coal numbers in parentheses opposite the appropriate members.

5. *Southwestern Illinois.*—This section is constructed mainly from data obtained in Perry and Jackson counties. It is noteworthy because it shows the beginning of the expansion that is most important below coal No. 2 and which becomes progressively greater across southern Illinois and western Kentucky. Except for thicker coals, this section is very similar to the development of corresponding strata between coal No. 2 and the Curlew (Seville) limestone, in parts of the northwestern portion of the Illinois coal field. In the areas of columns 3 and 4 many of these beds are absent and thus the Perry-

Jackson County section constitutes a connecting link between western and southern Illinois.

The important coals of this area are the Murphysboro seam, a double benched coal now largely mined out, and coal No. 6. The

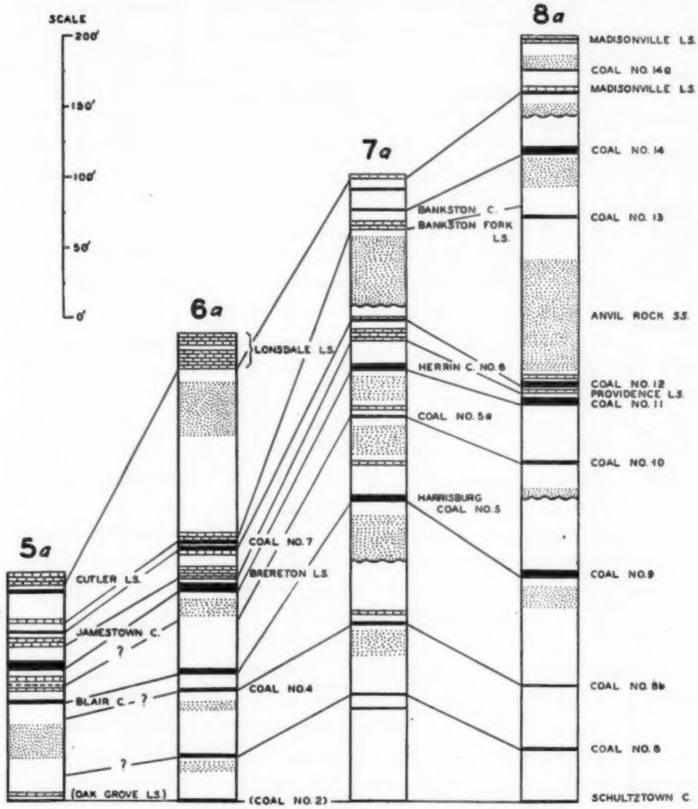

FIG. 4.—Columnar sections 5a, 6a, 7a, and 8a.

Blair coal, probably equivalent to the Harrisburg seam, is of minor importance.

6. *Central Illinois.*—The main coal-bearing strata in central Illinois are everywhere buried beneath a thick covering of younger beds and this column is, therefore, based on a study of deep borings and mine shafts. That part above coal No. 2 is comparable in thickness to

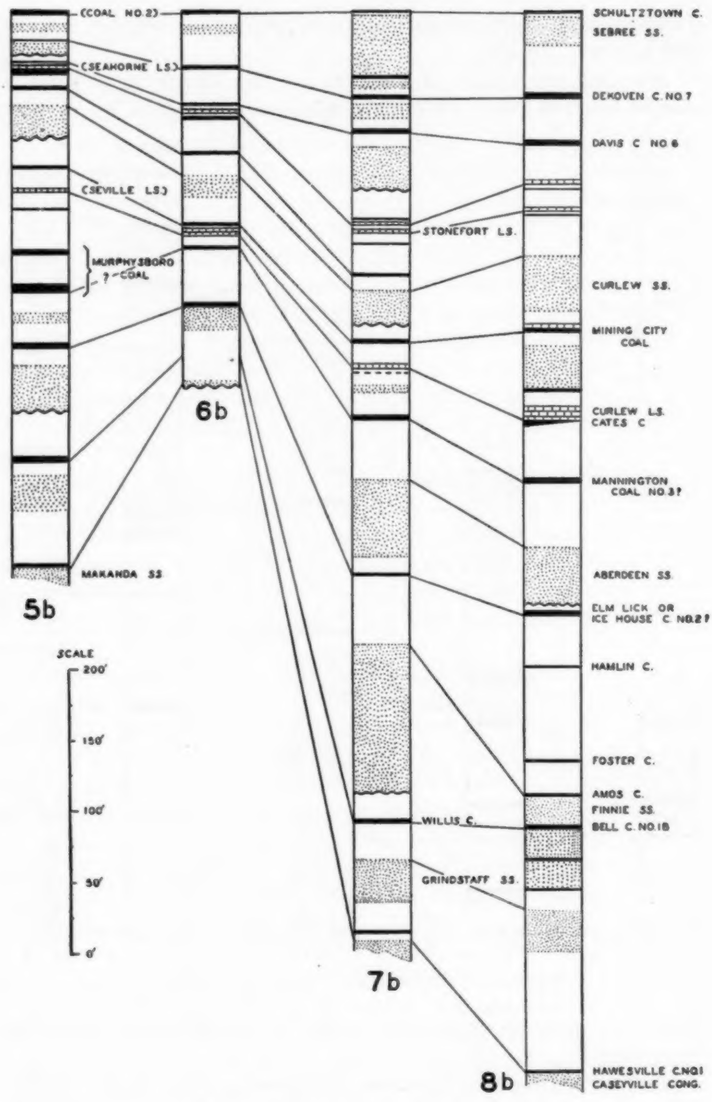

FIG. 5.—Columnar sections 5b, 6b, 7b, and 8b.

corresponding beds in the Illinois valley area as shown in column 2. Below coal No. 2, however, the section is similar but considerably thicker than that of column 2 and reflects the remarkable thickening of these lower beds that occurs southeastward across the basin. Coal No. 6 is the only important seam in this area although coal No. 1 (Murphysboro?) was formerly mined in Christian County from the deepest shaft in Illinois.

7. *Southern Illinois.*—This column illustrates the approximate maximum development of the middle part of the Coal Measures in Illinois. The entire section has expanded and numerous members absent or poorly developed in other parts of the state are here more or less persistently present. Among the more important of these are the Bankston and No. 5a coals and the Stonefort limestone which extend far into western Kentucky. Both the Herrin and Harrisburg coals are actively mined in this district and the DeKoven and Davis coals give promise of considerable future importance.

8. *Western Kentucky.*—This column illustrates the further expansion of the section that occurs eastward in western Kentucky. It is based mainly on observations in the western part of this field. It is not characteristic, therefore, of all of western Kentucky and probably does not indicate the maximum expansion occurring in that state.

By far the most important coal of western Kentucky is No. 9. The Mannington and No. 11 seams, whose equivalents are mined in Illinois, are important in certain areas. Coals No. 12 and No. 14, thin or absent in other parts of the basin, locally achieve minable thickness and considerable local importance.

Columns 9 to 12 (Fig. 6) show the development of the middle part of the Coal Measures along the eastern border of the Eastern Interior basin in southwestern Indiana and eastern Illinois. Correlation of the most important members is indicated by the introduction of Illinois names and coal numbers opposite them.

9. *Southern Indiana.*—This column is based upon outcrops and drill records in Gibson, Pike, and Dubois counties and is much thinner than that presented for western Kentucky. In this area the lower part of the section is thinning notably toward the north and several more coals are present between the Holland (Minshall) limestone and the Mansfield sandstone than occur farther north. The only important seam in this area is the Petersburg Coal V although years ago the much thinner Cannelton coal was extensively mined adjacent to the Ohio River.

10. *Sullivan and Greene counties, Indiana.*—This is the present standard section for Indiana. Coal V, known here as the Alum Cave

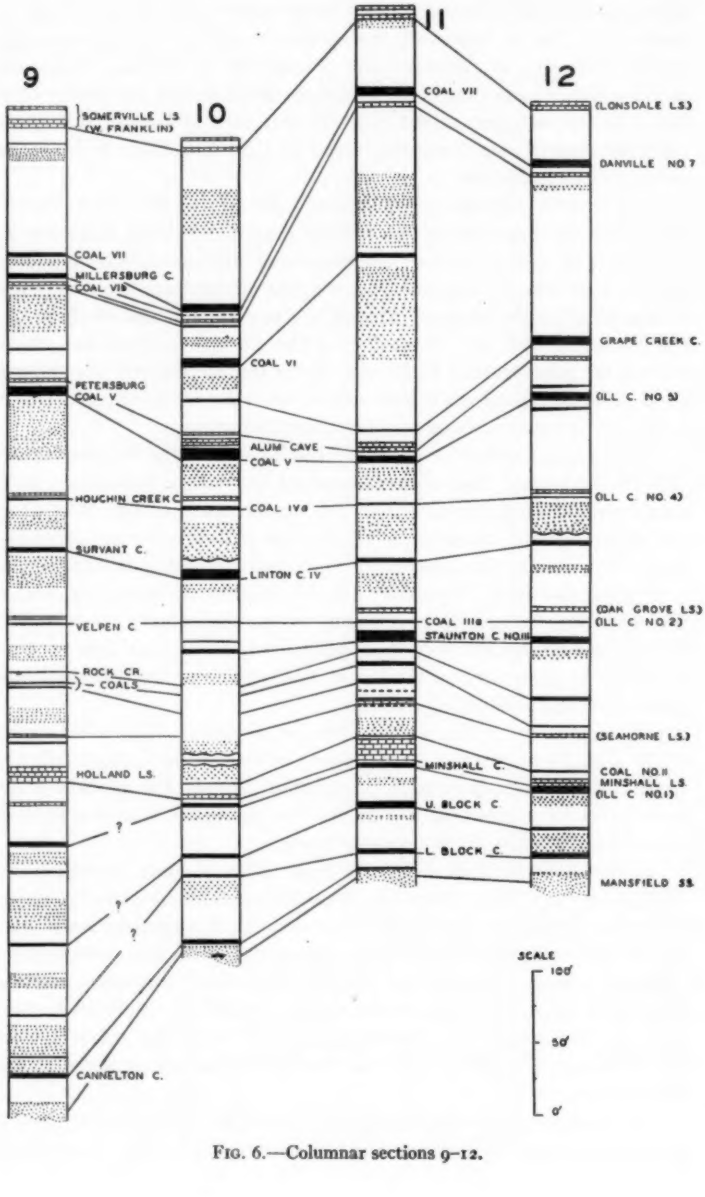

FIG. 6.—Columnar sections 9–12.

seam, persists as a thick coal across these counties and Coal VII has thickened from the south so as to be of some importance. These counties, however, are particularly noteworthy for the great development of Coals IV and VI which make this area one of the richest coal-bearing regions of the entire Eastern Interior basin.

11. *Vigo and Clay counties, Indiana.*—This is Ashley's original type section for the Indiana coal fields and the only area in which Coal III is of noteworthy commercial importance. Here also the coals beneath the Minshall limestone achieve their greatest development along the eastern border of the basin. Coals V and VII are present and minable in this area.

12. *Vermilion County, Illinois and Indiana.*—In this area the entire Coal Measures is thinning notably toward the north and many of the coals shown in this column disappear. The persistent Coals V and VII extend into this area but as Coal VII reaches its maximum development Coal V pinches out completely. This district also appears to possess the only minable body of the Grape Creek coal or its equivalents. The Minshall coal also achieves minable thickness in this area.

DESCRIPTIONS OF MINABLE COALS

Lower Brazil Block coal.—The lower Block coal is at present the first important coal overlying the Mansfield sandstone in Indiana and it achieves its greatest importance in Clay County where it is a splint coal and is extensively mined. It is correlated with the Bell coal, No. 1B of western Kentucky, the Willis coal of southern Illinois, and the Tarter coal of western Illinois. In Indiana and western Illinois this seam is irregular in development, being present with good thickness in more or less small areas from which it thins in all directions and is locally absent. In southern Illinois and western Kentucky, however, it is a more persistent but thin seam.

Upper Brazil Block coal.—The upper Block coal lies close above the lower Block in Clay County, Indiana, where it is likewise mined. It is also a splint coal. Farther south the interval between these seams expands and it is known as the Ice House coal, No. 2 of the western counties of Kentucky from which it has been traced into southern Illinois. Farther east in the western Kentucky coal field it is the Elm Lick coal. It is correlated with the Pope Creek coal of western Illinois. Like the lower Block it is irregularly developed in Indiana and western Illinois whereas farther south it is a more persistent but thin seam.

Rock Island No. 1 coal.—The Rock Island coal was formerly of much importance in the northwestern corner of the Illinois coal fields

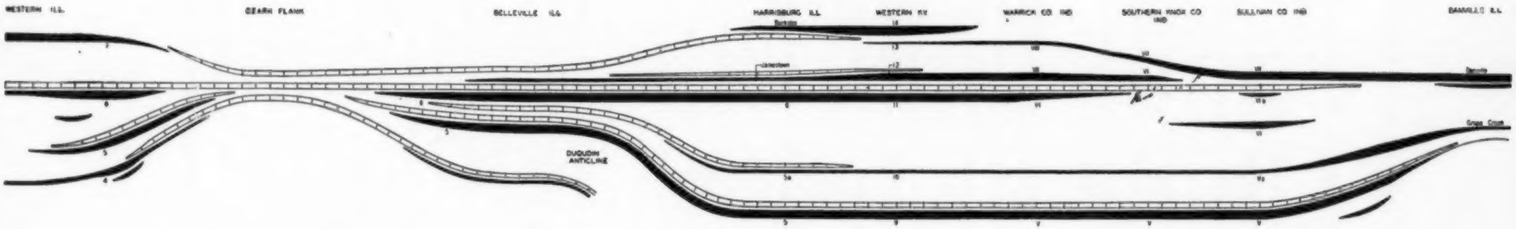

FIG. 7.—Cross section (not drawn to scale) around western, southern and eastern margins of Eastern Interior coal field showing relations of principal coal seams and their associated limestones.

but it is now largely mined out. Like the Block coals of Indiana it is irregularly distributed and lies in discontinuous areas separated by barren territory. It is correlated with the Minshall coal (Coal V of 1899) of Indiana and is probably equivalent to the Murphysboro No. 2 coal of southern Illinois, now mined out, and the Mannington coal of Christian County, Kentucky, which is locally an important seam. The Minshall coal has been stripped extensively and worked from many local shafts and entries but has nowhere been subjected to large-scale underground mining. Its thickness, which in some areas exceeds 6 feet, requires, however, that this seam be included among the minable coals of Indiana.

Both in the Rock Island district and in Indiana this coal is overlain by a conspicuous marine limestone of irregular development known by the names Seville and Minshall limestones respectively. This bed is also extensively developed in southern Illinois and western Kentucky as the Curlew limestone. In this southern area the limestone is believed to have risen in the section above the coal as the result of the introduction of members including a thin coal not present farther north. There is, however, some doubt regarding the correlation of the Murphysboro and Mannington with the Rock Island coal and they may actually belong at a slightly lower horizon.

Davis and Dekoven coals.—The Davis and Dekoven coals of southern Illinois and the adjacent part of western Kentucky are not at present commercial coals but their thicknesses of 4 feet or more throughout a considerable area and their good quality appear to guarantee their future importance. Outside of this area the Davis is a thin but persistent seam. The Dekoven coal is not quite so extensively developed but these two seams or their horizons have been recognized in outcrop almost completely around the basin.

Staunton Coal III.—Indiana Coal III is important only in a comparatively limited area in Clay and adjacent counties. Its barren horizon is believed to have been recognized a short distance below the Colchester No. 2 coal in western Illinois and a thin coal at this horizon is probably present in southern Illinois and western Kentucky.

Colchester No. 2 coal.—The Colchester coal is probably the most uniformly developed seam in the entire Eastern Interior basin. It has been opened at innumerable places in western Illinois but its thickness, which varies little from 30 inches, prevents it from being an important commercial coal at the present time. In northern Illinois it was formerly worked extensively from shafts where it is known as the La Salle "third vein" coal and reaches a thickness of $3\frac{1}{2}$ feet or

more. At present it is the basis of an enormous stripping operation. Southward it thins and is of little or no economic importance. It is known as Coal IIIa in the revised Indiana nomenclature and has been named Velpen in the area of the Ditney folio of the United States Geological Survey's geologic atlas. In western Kentucky this seam is known as the Schultztown coal.

This coal is overlain by a persistent black slaty shale above which occurs a very characteristic series of impure limestone bands bearing marine fossils and separated by shale. These limestone bands, black shale, and coal constitute one of the most readily recognized and stratigraphically important key horizons of the entire Coal Measures.

Linton Block Coal IV.—The Linton Block coal is important only in a comparatively restricted area embracing parts of Greene and adjacent counties in Indiana. South of this area it is somewhat thinner and is known as the Survant coal. In western Illinois near Alton and in northern Illinois near La Salle thin local coals occur that are at least approximately equivalent to this seam. It is probably equivalent to Coal No. 8 of western Kentucky.

Coal IVa, a thin seam next above the Linton Block in Indiana, is a very persistent bed that is known in western Illinois as coal No. 4. It is commonly overlain by black and locally slaty shale, and in western Illinois this is succeeded by marine limestone and the coal or its horizon has been widely identified. In Indiana the black shale is associated with a layer of dense black impure limestone and constitutes an easily recognized horizon; it is the Houchin Creek coal of the Ditney folio and Coal No. 8B of western Kentucky.

Harrisburg No. 5 coal.—The Harrisburg No. 5 coal is equivalent to western Kentucky Coal No. 9 and the Petersburg or Alum Cave Coal V of Indiana. According to most recent observations it is probably likewise equivalent to the Springfield No. 5 coal of western Illinois.[8] This seam is, therefore, the most important coal of the Eastern Interior basin. It is the principal coal mined in Indiana and western Kentucky and is second only to coal No. 6 in Illinois.

Coal No. 5, like coals No. 2 and No. 4 of Illinois and their equiva-

[8] The Springfield seam is the true No. 5 coal of the type section built up by Worthen in western Illinois. In the discussion of the geology of Saline County, published in volume 6 of the Worthen survey reports, the Harrisburg coal was identified as No. 5 and this number was consistently applied to it for more than 50 years. Later, stratigraphic studies in the area between the Springfield and southern Illinois mining districts appeared to show that the Harrisburg coal is equivalent to No. 4 rather than No. 5 and this correlation was published by the writers in 1932 (*Bull. Geol. Soc. America*, Vol. 43, pp. 1007, 1008). Recent work which has resulted in a better understanding of the Indiana section suggests that the 1932 correlation is incorrect and that the Springfield and Harrisburg coals are actually the same. This problem is not yet satisfactorily solved.

lents elsewhere, is generally overlain by black slaty shale and marine beds including persistent limestone. It or its horizon has been recognized almost continuously around the borders of the basin but is locally entirely absent in the area of much reduced section in west central Illinois and it is very inconspicuous in the Danville district.

Grape Creek coal.—The Grape Creek coal is important only in a very limited area south of Danville, Illinois. It continues southward through Indiana as a thin but persistent seam (Vb) and is equivalent to Coal No. 10 of western Kentucky and No. 5a of southern Illinois. It is unknown in western or northern Illinois[9] except as possible local developments principally of cannel coal in Stark and La Salle counties.

Coal VI.—Like Coals III and IV of Indiana, Coal VI is limited in development and is important only in part of Sullivan and adjacent counties in Indiana. Three rather persistent partings in this seam suggest that it is equivalent to Illinois coal No. 6 although such correlation is not made at this time because of the important interval separating it from the limestone cap rock of the latter seam and the intervention of another thin coal. This interpretation may not be correct because somewhat similar relations between a coal believed to be Herrin No. 6 and its cap limestone locally occurs in La Salle County, Illinois.

Herrin No. 6 coal.—The Herrin seam is the most important coal of southern and central Illinois and it attains the extraordinary thickness of 14 feet east of the Duquoin anticline in Franklin County. It thins out and disappears toward the northwest and becomes discontinuous at the north where it is known as the Streator or La Salle "second vein" coal but achieves minable thickness in certain small areas. It is equivalent to Kentucky No. 11 coal which in the western part of that state is second in importance only to Coal No. 9. It is probably Coal VIb of Indiana.

The Herrin coal is characterized throughout practically its entire extent by three persistent clay partings one of which is widely known as the "blue band." These partings are more extensive than the coal itself and may be recognized, separated by thin streaks of smut, at many places where no actual coal is present. This seam is overlain by dark shale and a marine limestone which persists far beyond the limits of the coal.

Coal No. 12.—This coal is important only in western Kentucky where it is mined in Hopkins and Muhlenberg counties. It continues,

[9] In 1932 (*op. cit.*) the writers correlated the Grape Creek and Springfield No. 5 coals. The Grape Creek coal, however, definitely overlies the Harrisburg coal and the present correlation of the latter bed with the Springfield seam forces the conclusion the previous correlation is incorrect.

however, as a thin seam which is persistent throughout southern and central Illinois where it is known as the Jamestown coal and in the southern half of the Indiana coal fields where it is termed the Millersburg seam which has been incorrectly correlated with Coal VII. This seam lies close above the Herrin coal and at many places they are separated by little more than the limestone cap rock of coal No. 6.

Danville No. 7 coal.—The Danville coal, Illinois No. 7 coal, Indiana Coal VII, is at present principally worked in the Danville district in large strip mines. It thins out both toward the northwest and south and is absent in southern Illinois and parts of western Kentucky. In the latter area, however, it may be the seam that is locally known as No. 13. It was formerly worked by shaft at a few places in northern Illinois where it was known as the La Salle "first vein." This, like several of the lower seams, is overlain by black shale above which marine limestone may or may not be present. In general the limestone is best developed where the coal is thin or absent.

Coal No. 14.—This seam is important only in western Kentucky where it is worked in large mines principally in Hopkins County. It is apparently discontinuous and there is some uncertainty regarding the equivalence of coals in different parts of this district that are known as Baker, Nebo, and No. 14. It is tentatively correlated with the Bankston coal of southern Illinois, a thin seam that is undeveloped in other parts of that state.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 23, NO. 9 (SEPTEMBER, 1939), PP. 1393-1403, 3 FIGS.

JACKSON EOCENE FROM BORINGS AT GREENVILLE, MISSISSIPPI[1]

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ABSTRACT

The occurrence of Jackson beds at shallow depth beneath Greenville, Mississippi, furnishes an important clue to subsurface structural conditions under the broad alluvially masked Mississippi River valley. Borings recently drilled there by the Mississippi River Commission passed through approximately 100 feet of Recent alluvium before penetrating fossiliferous Jackson Eocene sediment. Samples from the borings, studied for microfossils, indicate that the Jackson beds comprise the lower part of the *Textularia hockleyensis* zone and the upper part of the *Textularia dibollensis* zone. The contact of these zones dips westward toward the Arkansas syncline whose axis can be traced southward around the eastern margin of the Monroe uplift. The date of synclinal downwarping of the Jackson beds is considered to be Miocene.

INTRODUCTION

The Mississippi alluvial valley presents a major obstacle to geological interpretation of the Mississippi embayment region. Not only is the valley underlain by a thick Quaternary alluvial sequence which effectively masks the underlying Tertiary sediment but its great width obscures regional structures indicated by outcrops flanking the valley walls.

The alluvial valley widens north of the Miocene outcrop between Sicily Island, Louisiana, and Natchez, Mississippi, where the width of the valley is approximately 30 miles. In the region of the Jackson Eocene outcrop between Drew County, Arkansas, and Yazoo County, Mississippi, the width of the Quaternary sediment has reached 80 miles. Farther north the Arkansas River valley enters the Mississippi and the width of the combined valley systems is more than 130 miles between outcrops of the Wilcox Eocene. North of the Mississippi-Arkansas valley confluence Crowleys Ridge and its extensions divide the alluvial valley into separate basins which converge northward at the apex of the Mississippi embayment near Cairo, Illinois.

The only detailed information concerning the Tertiary sediments in this wide alluvial region is obtained from the comparatively few borings which have been drilled through the Quaternary sediment. These borings are limited mainly to areas of oil exploration, water-supply investigation, and areas in which the Mississippi River Commission flood-control surveys have been made. Most of the detailed stratigraphic information has come from borings in search of oil where such geologic information is paramount.

[1] Manuscript received, May 29, 1939.

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The writer was fortunate, therefore, in obtaining a set of middle Jackson Eocene cores, taken at approximately 100-foot depths in six borings along the waterfront at Greenville, Mississippi. He is indebted to the Vicksburg Engineer District and the Mississippi River Commission under whose general supervision the aforementioned borings were made, and to William H. Jervis, associate engineer, and Ronald Mabrey, junior engineer, of the Soil Section, Vicksburg Engineer District, for samples and logs of borings; and to H. V. Howe, director, School of Geology, Louisiana State University, for identification of the microfossils which were washed from these cores.

Throughout the Gulf Coast region the Jackson Eocene is a highly fossiliferous group of rocks which has been zoned in detail primarily on the basis of foraminiferal studies. In this region the following zones are generally accepted: upper Jackson, *Valvulineria texana, Massilina pratti;* middle Jackson, *Textularia hockleyensis, Textularia dibollensis;* lower Jackson, *Camerina moodybranchensis, Operculina vaughani.* Hence the stratigraphic position of each fossiliferous core in the Greenville borings was easily developed although none of the borings penetrated the Jackson for more than a few feet. The presence of Jackson Eocene at depth at Greenville should be of general interest because it has not been previously reported from the area and because it points to some interesting structural relationships.

LOCATION AND GENERAL GEOLOGIC RELATIONSHIP OF BORINGS AT GREENVILLE

Greenville, Mississippi, is located on Bachelor Bend, a recently abandoned course of the Mississippi River. It lies within the alluvial valley of the Mississippi River approximately 55 miles northwest of the outcrop of the Jackson Eocene at Yazoo City, Mississippi, and 35 miles east of the Jackson outcrop in Drew County, Arkansas. (For the location of Greenville with respect to the outcrop of Jackson sediment in the Mississippi embayment, see the generalized map, Fig. 1.)

The borings along the waterfront at Greenville (Fig. 2) were spaced at 1,500-foot intervals and were drilled to depths varying between 98 and 116 feet. They were projected into the north-north-east-south-southwest line *AA'* of Figure 2 which forms the base line for plotting the logs (Fig. 3).

The sequence of Recent alluvium recorded on the logs of the borings is shown graphically on Figure 3. Each log recorded an upward gradation from coarse lenticular sands and gravels at the base through medium and fine sands into a group of sandy silts and silty clays near

the upper surface. This gradational sequence is very similar to that encountered in many other borings within the alluvial valley of the Mississippi River and is believed by the writer[3] to reflect a gradual decrease in stream gradient since the maximum advance of the late Wisconsin ice.

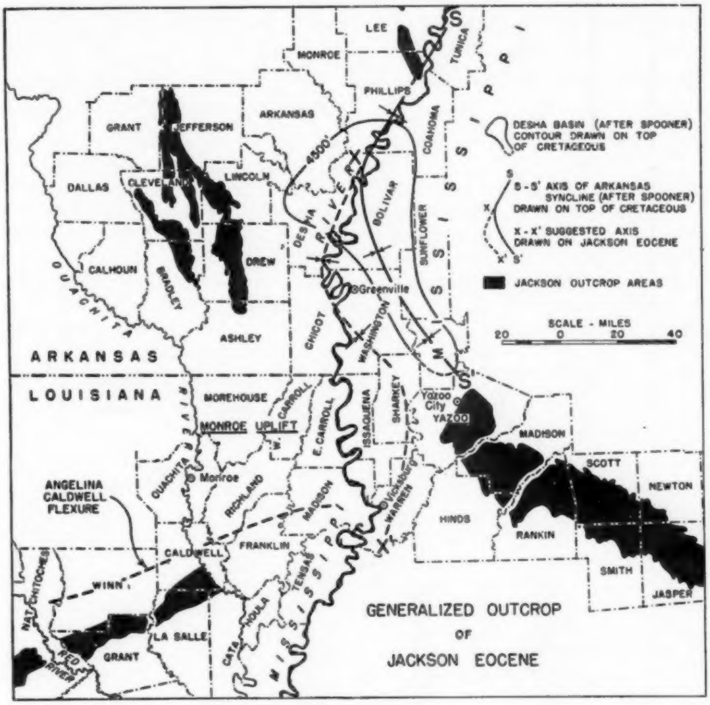

Fig. 1.—Generalized outcrop of Jackson Eocene and main structural features within Mississippi embayment.

A predominant gray color of the alluvial sediments reflects their Mississippi River origin. Within the fine-grained sediments near the upper part of the typical gray sequence, however, tan sediments point to a mixing of Arkansas and Mississippi River materials.

The Jackson Eocene sediment varies from carbonaceous clays to silty, or sandy, glauconite-bearing clays containing a few small gas-

[3] H. N. Fisk, "Igneous and Metamorphic Rocks from Pleistocene Gravels in Central Louisiana," *Jour. Sed. Petrology*, Vol. 9, No. 1 (April, 1939), pp. 20–27.

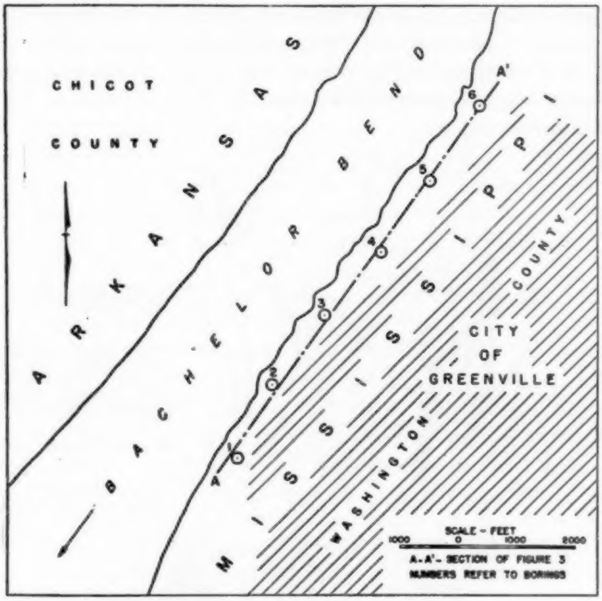

FIG. 2.—Location of borings at Greenville, Mississippi.

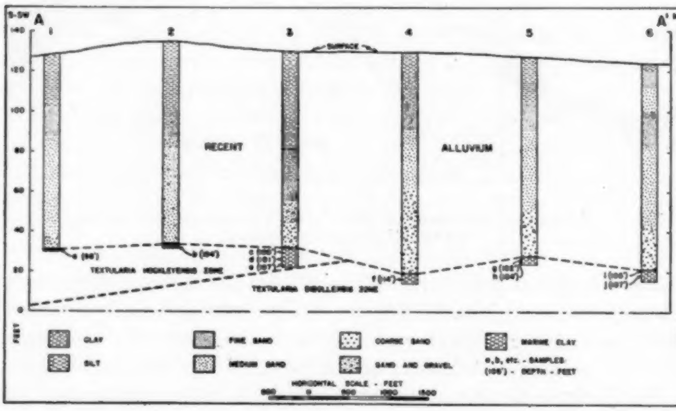

FIG. 3.—Cross section showing thickness of Recent alluvium and position of Jackson Eocene samples in each boring at Greenville, Mississippi. For location of borings see Figure 2.

tropods, pelecypods, and scaphopods. Megafossils are, however, rare as compared to the excellent assemblage of Foraminifera and Ostracoda. In the following list of samples taken from the cores of Jackson sediment, the samples are lettered to correspond to the sample positions shown on Figure 3 and also to correspond to the letters following the species of Foraminifera and Ostracoda on the check list. An additional sample Y from Yazoo City, Mississippi, has been added so that the fauna from the borings may be checked with a surface sample; the fauna as listed from this sample has been taken from the check list published by Monsour.[4]

Sample A—depth, 98 feet (Boring 1; elevation, 128.3 feet M. G. L.). Dark bluish gray carbonaceous fossiliferous clay

Sample B—depth, 104 feet (Boring 2; elevation, 135.1 feet M. G. L.). Dark-gray fossiliferous clay containing flecks of carbonaceous material

Sample C—depth, 100 feet (Boring 3; elevation, 130 feet M. G. L.). Light-gray friable fossiliferous siltstone containing weathered glauconite grains

Sample D—depth, 101 feet (Boring 3). Dark-gray fossiliferous silty clay containing fine lentils of medium sand and coarse glauconite particles

Sample E—depth, 107 feet (Boring 3). Dark-gray carbonaceous fossiliferous clay with weathered glauconite particles

Sample F—depth, 114 feet (Boring 4; elevation, 129.7 feet M. G. L.). Light-gray micaceous-glauconitic fossiliferous clay

Sample G—depth, 102 feet (Boring 5; elevation, 127.5 feet M. G. L.). Light-gray glauconitic fossiliferous silty clay

Sample H—depth, 104 feet (Boring 5). Dark-gray fossiliferous clay with scattered grains of medium sand and coarse glauconite

Sample I—depth, 104 feet (Boring 6; elevation, 104 feet M. G. L.). Light-gray fossiliferous siltstone slightly cemented by secondary calcite

Sample J—depth, 108.5 feet (Boring 6). Dark-gray fossiliferous silty clay containing scattered grains of glauconite and mica flakes

Sample Y—Yazoo clay of Jackson Eocene, Yazoo City, Mississippi. In railway cut on Highway 49, west of town of Yazoo City, about ¼ mile from west edge of town. Sample taken on south side of railway track about 30 feet above mean water level of Yazoo River. Karl E. Young Loc. 12

TABLE I

CHECK LIST OF FORAMINIFERA AND OSTRACODA FROM BORINGS

FORAMINIFERA

Ammodiscus incertus (d'Orbigny), b
Anomalina costiana Weinzierl and Applin, Y
    danvillensis (Howe and Wallace), c, d, e, h, Y
    jacksonensis (Cushman and Applin), i
        var. *texana* (Cushman and Applin), a, b, c, d, e, f, g, h, i, j, Y
Asterigerina var., d
Bolivina gracilis (Cushman and Applin), a, b, c, d, e, f, g, h, i, j, Y
    jacksonensis (Cushman and Applin), a, b, c, e, f, g, h, i, j, Y
    sp.—c, f

[4] Emil Monsour, "Micro-paleontologic Analysis of Jackson Eocene of Eastern Mississippi," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 21, No. 1 (January, 1937), pp. 80–96.

Bulimina jacksonensis (Cushman), a, f
ovata d'Orbigny, a, b, c, d, e, f, g, h, i, j
Bitubulogenerina mauricensis Howe, Y
Buliminella basistriata var. *nuda* Howe and Wallace, b, c, d, e, f, g, h, i, j
elegantissima (d'Orbigny), b
Cassidulinoides braziliensis (Cushman), a, Y
danvillensis Howe and Wallace, i
lobatulus (Walker and Jacob), c, d, f, g, h, Y
Cornuspira involvens (Ruess), Y
Cornuspira olygogyra Hantken, i
Cibicides lobatulus (Walker and Jacob), Y
mississippiensis (Cushman), Y
yazooensis (Cushman), Y
Dentalina communis d'Orbigny, Y
filiformis (d'Orbigny), Y
sp., h
Discorbis alveata Cushman, Y
assulata Cushman, b, c, f, h, j
globulo-spinosa Cushman, e
hemisphaerica Cushman, a, b, d, e, f, g, h, j
sp., h
Entosolenia laevigata (Reuss), Y
Eponides jacksonensis (Cushman and Applin), a, b, c, e, f, g, h, j, Y
Glandulina laevigata d'Orbigny, i, j
Globigerina bulloides d'Orbigny, a, b, e, g, j
danvillensis Howe and Wallace, a, b, c, e, g, j
sp., a, b, c, d, e, f, g, h, i
Globulina gibba d'Orbigny, a, b, c, d, e, f, h, i, j, Y
var. *tuberculata* d'Orbigny, c, d, f, g, h, j, Y
Globulina minuta (Roemer), a, d, f, g, h, i, j
sp., a, b, c, d, e, g, h
Gumbelina cubensis Palmer, Y
Guttulina austriaca d'Orbigny, a, b, c, d, g, i, Y
Guttulina irregularis d'Orbigny, a, d, Y
Guttulina spicaeformis (Roemer), c
Gyrodina danvillensis Howe and Wallace, a, b, c, e, g, h, j
Haplophragmoides sp., b
Hantkenina alabamensis Cushman, Y
Karreriella sp. 1, h, i
sp. 2, g, j
Lagena aculicosta Reuss, c, f, g, i
costata (Williamson), Y
globosa (Montague), Y
ouachitaensis Howe and Wallace, a, b
Marginulina fragaria var. *texasensis* Cushman and Applin, g, h, Y
Massilina decorata Cushman, Y
Massilina goniopleura Hadley, a, b, d, e, f, h, i, j
Nodosaria longiscata d'Orbigny, d, g, h
vertebralis Batsch, b, i
Nonion advenum (Cushman), a, j
applini Howe and Wallace, e, f, h
chapapotense Cole, b, c, d, e
inexcavatum Cushman and Applin, d
micrum Cole, b, c, d, e, f, g, h, i, j, Y
cf. *planatum* Cushman and Thomas, a, b, c, d, e, g, h, j, Y
Nonionella cockfieldensis Cushman and Ellisor, a (reworked)
danvillensis Howe and Wallace, Y
hantkeni var. *spissa* Cushman, a, b, c, d, f, g, h, i, j
jacksonensis Cushman, a, e, g, h, i, j, Y
Polymorphina advena Cushman, b, c, e, h, Y
Patellina, Y
Pulvinulinella danvillensis Howe and Wallace, a, b

Quinqueloculina laevigata d'Orbigny, i
seminula (Linne), b, d, e, j
Ramulina globulifera Brady, Y
Reussella, sp., d, h
Robertina sp., a, b, i
Robulus alato-limbatus (Gumbel), Y
articulatus var. *texanus* (Cushman and Applin), a, c, e, g, h, j
limbosus (Reuss), Y
Sigmomorphina jacksonensis (Cushman), a, b, e, g, h, i, j
var. *costifera* Cushman and Ozawa, c, f, i, j, Y
Siphonina advena var. *eocenica* Cushman and Applin, f, h, i
danvillensis Howe and Wallace, b, e, Y
jacksonensis Cushman and Applin, e
var. *limbosa* Cushman, a, c, d, g, j
Spirillina sp., j
Textularia adalta Cushman, f, i, Y
dibollensis Cushman and Applin, g, i, j
var. *humblei* Cushman and Applin, a, b, c, e, f, h
hockleyensis Cushman and Applin, b, Y
mississippiensis Cushman, a, b, c, d
var. *rhomboidea* (Cushman and Ellisor), g, h, i, j
var. *alabamiensis* (Cushman), c, e, f
Trifarina bradyi var. *advena* Cushman, h
Triloculina sp. (ribbed), h
Tritubulogenerina sp., g
Uvigerina dumblei, c, f, h
gardnerae Cushman, a, c, d, e, i, Y
var. *texana* Cushman and Applin, Y
Virgulina dibollensis Cushman and Applin, a, b, c, e, f, g, h, i, j, Y
recta (Cushman), b, d

OSTRACODA

Archicythereis yazooensis (Howe and Chambers), c, f, h, j
Brachycythere watervalleyensis Howe and Chambers, a, b, c, d, e, f, g, h, i, j, Y
Buntonia shubutaensis Howe, a, b, c, e, f, Y
Bythocypris ? gibsonensis Howe and Chambers, f, g, h, i, j
Cythereis ? catahoulana Howe and Pyeatt, b, f, h, Y
deusseni Howe and Chambers, a, c, d, e, f, h, i, Y
florienensis Howe and Chambers, a, b, c, d, f, g, h, i, Y
gibsonensis Howe and Chambers, a, b, c, d, e, h, i, j
hysonensis Howe and Chambers, b, d, e, j, Y
? *jacksonensis* Howe and Pyeatt, a, d, e, f, h, i, j, Y
montgomeryensis Howe and Chambers, a, c, d, e, g, i, j
yazooensis Howe and Chambers, Y
Cytherella sp., h, Y
Cytherelloidea danvillensis Howe, b, c, d, g, h, j, Y
montgomeryensis Howe, d, h, j
Cytheretta alexanderi Howe and Chambers, f, h, Y
Cytheridea (*Clithrocytheridea*) *grigsbyi* Howe and Chambers, f
(*Haplocytheridea*) *ehlersi* (Howe and Stephenson), Y
(*Haplocytheridea*) *montgomeryensis* Howe and Chambers, a, b, c, d, e, f, g, h, i, j, Y
Cytheromorpha ouachitaensis Howe and Chambers, c, d, e
n. sp., b
Cytheropteron montgomeryensis Howe and Chambers, a, c, e, f, g, h, i, j, Y
Eocytheropteron spurgeonae Howe and Chambers, d, h, j
jacksonensis Howe and Chambers, a, b, c, d, e, h, i, Y
Loxoconcha jacksonensis Howe and Chambers, a, b, c, d, e, h, i
Paracypris franquesi Howe and Chambers, f, h, Y
Pyricythereis israelskyi (Howe and Pyeatt), a, b, c, e, f, g, j, Y
var. *moresi* Howe and Pyeatt, a, d, f, h, Y
var. *warneri* Howe and Pyeatt, j, Y

STRATIGRAPHIC POSITION OF JACKSON SAMPLES

The lithologic character of the Jackson sediment in the borings is comparable with that of beds described by Lowe[5] from the type locality of the Yazoo clays near Yazoo City, Mississippi. They are also lithologically similar to the transition sediment between the clays bearing *Textularia dibollensis* and the overlying silty and sandy carbonaceous clays carrying *Textularia hockleyensis*, and to marine tongues of sediment within the upper part of the *Textularia hockleyensis* zone in central Louisiana.

The fauna from these beds has been listed by the writer[6] from Grant and La Salle parishes and by Monsour[7] from the Jackson beds exposed along the Ouachita River, Catahoula Parish, Louisiana. Monsour's check lists and excellent faunal analyses of the Jackson beds form the basis for much of the faunal comparison in the present paper.

The faunal assemblage of Foraminifera and Ostracoda from the northern borings (Nos. 4, 5, and 6) at Greenville is very similar to that listed by Monsour from the exposure of Yazoo clay at Yazoo City, Mississippi, and from the upper part of the Cocoa sand in eastern Mississippi. The species identified from these borings are typical of those which characterize the *Textularia dibollensis* zone of Louisiana and Mississippi. Because no fossils found in the Greenville borings or in the exposure at Yazoo City are diagnostic of the lower Jackson Moody's Branch marl beds except a reworked, pyritized *Nonionella cockfieldensis*, the samples must be from beds well toward the top of the zone.

Samples from the southern borings (Nos. 1, 2, and 3) at Greenville contain *Textularia hockleyensis* or *Nonion chapapotense*, diagnostic fossils from estuarine tongues within the upper part of the *Textularia hockleyensis* zone in central Louisiana.[8] These tongues contain, in addition to *Nonion chapapotense*, fossils such as *Valvulineria texana* and *Virgulina danvillensis* which do not occur in beds lower than the "*Pecten-Bryozoan* horizon" of eastern Mississippi. None of these fossils has been reported from the clays at Yazoo City. Furthermore, the samples from the southern borings at Greenville are limited in upward extent by the absence of any fossils diagnostic of the upper Jackson Eocene, either from the upper Danville Landing beds of Louisiana or from the "*Lenticulina* horizon" of eastern Mississippi.

[5] E. N. Lowe, "Geology and Mineral Resources of Mississippi," *Mississippi Geol. Survey Bull. 20* (1925), p. 79.

[6] H. N. Fisk, "Geology of Grant and La Salle Parishes," *Louisiana Dept. Cons. Geol. Bull. 10* (1938), pp. 98–111.

[7] Emil Monsour, *op. cit.* See check list Loc. 1 (C, D, E) and Loc. 2.

[8] H. N. Fisk, *op. cit.*, p. 105.

THICKNESS OF SECTION

The Greenville borings expose a stratigraphic sequence equivalent to about 25 feet of the middle Jackson section in eastern Mississippi and to 120 feet in central Louisiana. Because the deposits thicken westward across Mississippi it is assumed that the Greenville section beneath the flood plain is also thicker than that exposed in eastern Mississippi. Fortunately the writer was able to check this assumption by drawing a hypothetical contact between the beds carrying the *Textularia hockleyensis* fauna in the three southern borings and those carrying the *Textularia dibollensis* fauna in the three northern borings. The contact line (shown on Fig. 3) was drawn as nearly horizontal as possible. The resultant component southwest dip parallel to AA', approximately 35 feet per mile, permits the reconstruction of a middle Jackson section approximately 60 feet thick.

GENERAL STRUCTURAL CONSIDERATIONS

The main structural features of that part of the Mississippi embayment in southeast Arkansas, northeast Louisiana, and west-central Mississippi are the Monroe uplift, centered in Morehouse Parish, Louisiana, and the Desha basin of the Arkansas syncline on the north in Desha County, Arkansas (Fig. 1).

Spooner,[9] who named the Arkansas syncline, refers to it as follows.

> The Arkansas syncline, a restricted part of the upper Mississippi embayment, includes most of eastern Arkansas north of Bradley, Drew, and Chicot counties. It is a broad synclinal trough, plunging gently southward along its axis which closely follows the course of the Mississippi River into northern Desha County where it is deflected by the Monroe uplift and trends slightly east of south into Mississippi.

Spooner dates the formation of both the Arkansas syncline and the Monroe uplift from the Upper Cretaceous, deformation being greatest during the deposition of the Lower and Middle Eocene Wilcox and Claiborne groups. He believes, however, that the forces that shaped the Monroe uplift were those that formed the Angelina-Caldwell flexure on the southern edge of the uplift.

The Jackson Eocene reflects some of the late deformational effects associated with these structural areas. South of the Monroe uplift the Jackson Eocene strikes northeastward across central Louisiana and crops out finally along the Ouachita River in southern Caldwell Parish. Northeast of the outcrop a complete section of Jackson has been reported in isolated borings beneath the Mississippi valley allu-

[9] W. C. Spooner, "Oil and Gas Geology of the Gulf Coastal Plain in Arkansas," *Arkansas Geol. Survey Bull. 2* (1935), pp. 136–37.

vium in southern Franklin Parish and in northern Tensas Parish.[10] A complete Jackson section has also been reported from Elliot's Parker well No. 1 in southwestern Warren County, Mississippi. From this well the Jackson Eocene can be traced northeastward to the surface outcrops of a complete Jackson section exposed in Warren and Yazoo counties, Mississippi. The strike of the beds in these counties can be traced southeastward across Mississippi into Alabama. The strike direction changes from southwest to southeast beneath the alluvial cover of the Mississippi valley near the eastern margin of the Monroe uplift. The change in strike direction points to a broad gentle downwarp about an axis trending south-southwest and located beyond the Mississippi alluvial valley, slightly east of Vicksburg.

Although the exact location of the synclinal axis is unknown, its position may be tentatively established in central Sharkey and Warren counties, Mississippi, because it is known from surface exposures that the beds in west-central Mississippi dip southwestward and because an easterly and southeasterly dip away from the Monroe uplift and toward west-central Mississippi has been accurately shown by Fergus[11] in his discussion of the Monroe gas field. The dips away from the Monroe uplift have been measured on the upper Claiborne-Cockfield formation. They are very gentle but should be sufficient to bring down the Jackson-Cockfield contact to a point where it could be encountered in borings beneath the Mississippi alluvium in Issaquena County, Mississippi. This assumption is supported by Munroe[12] who believes that the O'Brien Bros. well No. 1, located in east-central Issaquena County near the Sharkey County line, penetrated the Tertiary sediment near the Jackson-Claiborne contact and that it is entirely possible that the Jackson may have been scoured away locally by the Mississippi River.

It is probable that the axis of downwarp bends northwestward around the margin of the Monroe uplift and is downwarped toward the Desha basin in southeastern Arkansas. (See Fig. 1.) Several lines of reasoning support this assumption. First, the Jackson-Claiborne contact exposed in Cleveland and Bradley counties, Arkansas, strikes southeastward around the northern edge of the Monroe uplift and the dip is sufficiently great to bring down a considerable section of Jackson which Spooner reports beneath the alluvium in Arkansas, Desha, Lincoln, Jefferson, and Monroe counties, Arkansas. In Lincoln

[10] W. D. Chawner, "Geology of Catahoula and Concordia Parishes," *Louisiana Dept. Cons. Geol. Bull. 9* (1936), pp. 148–51.

[11] Preston Fergus, "Monroe Gas Field, Louisiana," *Geology of Natural Gas* (*Amer. Assoc. Petrol. Geol.*, 1935), pp. 741–72.

[12] D. J. Munroe, geologist, Sun Oil Company (personal communication).

County he estimates the thickness as between 250 and 400 feet. Secondly, the dip of the Jackson is south-southwest from Lee County, Arkansas, on the northeast, where the Jackson-Claiborne contact is exposed, through Phillips County toward the axis of the Arkansas syncline. Thirdly, although Spooner reports no Jackson beneath the alluvium in Chicot County, Arkansas, it is quite obvious that a considerable section exists in northern Chicot County because of the thick section encountered directly across the Mississippi River in the borings at Greenville. No Jackson beds are exposed here but the dip must be northward (away from the regional strike) and toward the synclinal axis.

The true dip at Greenville is indeterminable on the basis of existing information but because the beds there are much lower in elevation and higher stratigraphically than those exposed at Yazoo City on the southeast, it is assumed that it is in a more westerly direction than is indicated by the section AA' and that it is toward a syncline whose axis XX' is shown on Figure 1.

The evidence seems fairly conclusive that the Greenville borings penetrated Jackson sediment near the axis of a syncline which may deepen toward the north in the Desha basin and continue southward around the edge of the Monroe uplift into west-central Mississippi. The fact that the strike of the Claiborne Eocene and the overlying Jackson Eocene beds is the same in the Mississippi embayment indicates that both groups of Eocene sediment suffered the same deformational history. Likewise, the post-Jackson doming of the Monroe uplift as established by Spooner can be extended in time to post-Vicksburg because the regional seaward dip of the Jackson and Vicksburg in the Mississippi embayment is identical.

The Arkansas syncline opens southward and the dips of all Oligocene and Eocene beds abruptly steepen with the Angelina-Caldwell flexure. The line of steepening of beds is slightly north of the apex position of the enormously thick deltaic masses of the Miocene. It is the assumption of the writer that at least the latest uplift of the Monroe area was a compensative movement for downwarping beneath the thick Miocene deltaic masses. Its close corollary is the highland of southwest Mississippi which has been upwarped north of the Mobile-Tunica flexure[13] as a compensation[14] for downdragging of the thick Quaternary deltaic mass south of the Florida parishes, Louisana.

[13] H. V. Howe, "Louisiana Petroleum Stratigraphy," *Oil and Gas Jour.*, Vol. 34, No. 48 (April, 1936), pp. 98–111, 124–28; *Louisiana Dept. Cons. Gen. Minerals Bull. 27* (July, 1936), pp. 1–46.

[14] H. N. Fisk, "Pleistocene Exposures in Western Florida Parishes, Louisiana," *Louisiana Dept. Cons. Geol. Bull. 12* (1938), pp. 3–25.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 23, NO. 9 (SEPTEMBER, 1939), PP. 1404-1411, 2 FIGS.

STUDY GROUP REPORTS

PREFACE

With this issue of the *Bulletin* the editorial board of the A.A.P.G. is continuing a new series of informative articles entitled "Study Group Reports." We feel that it is eminently desirable to supply condensed information on practical petroleum geology problems and at the same time furnish information which is up to the minute in character.

One of the geological societies affiliated with the A.A.P.G. is the Houston Geological Society. They conceived the idea of establishing specialized groups to study certain definite problems and report on them at stated intervals of time. The subjects which were selected for special study are the following.

Surface geology	Geophysics
Subsurface geology	Structural geology
Paleontology	Mechanical well surveying
Stratigraphy	Evaluation
Sedimentation	Statistics
Paleogeography	Economics
Exploitation geology	Topography
Aerial geology	Electrical well surveying
Soil analyses	

A card was sent to approximately 300 members of the society, requesting each member to indicate which study group he preferred to join. A place was provided for first, second, and third choice. Subsequently, a steering committee of the society grouped the members according to their choice and selected a leader for each group. After studying their problem for two or three months, the conclusions reached by a certain group were put into brief form. These briefs were then published on mimeographed sheets and distributed.

With the permission of the Houston Geological Society and the members of the various groups involved, it is our privilege to republish some of these group reports. The first two have appeared in the August *Bulletin*. After reading the reports, the editor is anxious to hear from as many readers as possible to get an expression of opinion regarding (1) the desire of the members to see more of these in print, and (2) the possibility of establishing other similar study groups in other parts of the country.

W. A. Ver Wiebe

DATUM PLANES FOR CONTOURING THE GULF COAST REGION

REPORT OF HOUSTON GEOLOGICAL SOCIETY STUDY GROUP

STUDY GROUP MEMBERS

Shirley L. Mason, leader, E. W. K. Andrau, Hillard W. Carey, Frank G. Evans, Cecil D. Hagen, Harry W. Johnston, Harry Kilian, W. W. Patrick, J. A. Wheeler.

PURPOSE

The group selected the datum planes most valuable for regional subsurface contour maps in the Gulf Coast. It decided the relative importance of these and outlined the areas the individual maps should cover. A base map of the Gulf Coast from the Rio Grande to Alabama was marked to show the location and areal extent of the more important contour maps and of some others of minor importance.

Particular attention is called to the fact that the selection is made for regional maps only. The selection of contour planes for field maps, or those of restricted localities, should be based on the local columnar section and the depths considered most important locally.

ACKNOWLEDGMENTS

Acknowledgment is made to the companies coöperating in the Houston Cross Section Project for the negative of the outline base map, and to colleagues who contributed useful information.

TERMINOLOGY

The terms, formation names, *et cetera,* in this report are used in their present-day, subsurface sense. For this purpose it is not important that the terms be correct or that they can be correlated with surface formations of the same name. Those used are simply the least confusing. The same rule of present usage applies to the major stratigraphic divisions. The members of the study group accept no responsibility for these terms; formations listed under Oligocene may actually be Miocene, or *vice versa,* without altering the decisions made here.

MAP

The areas covered by the contour maps of primary importance are outlined on the base map by distinctive lines. Some of the minor ones are indicated by thinner lines.

DISCUSSION OF PLANES

MIOCENE

For the present, there are no planes in the Miocene that are considered of major importance. There are three that should be mentioned.

Marine faunal zone (or zones).—In the coastward areas, particularly in Louisiana, where the "middle Marine" (Oligocene) shales are below normal drilling depths, paleontologists have selected faunal

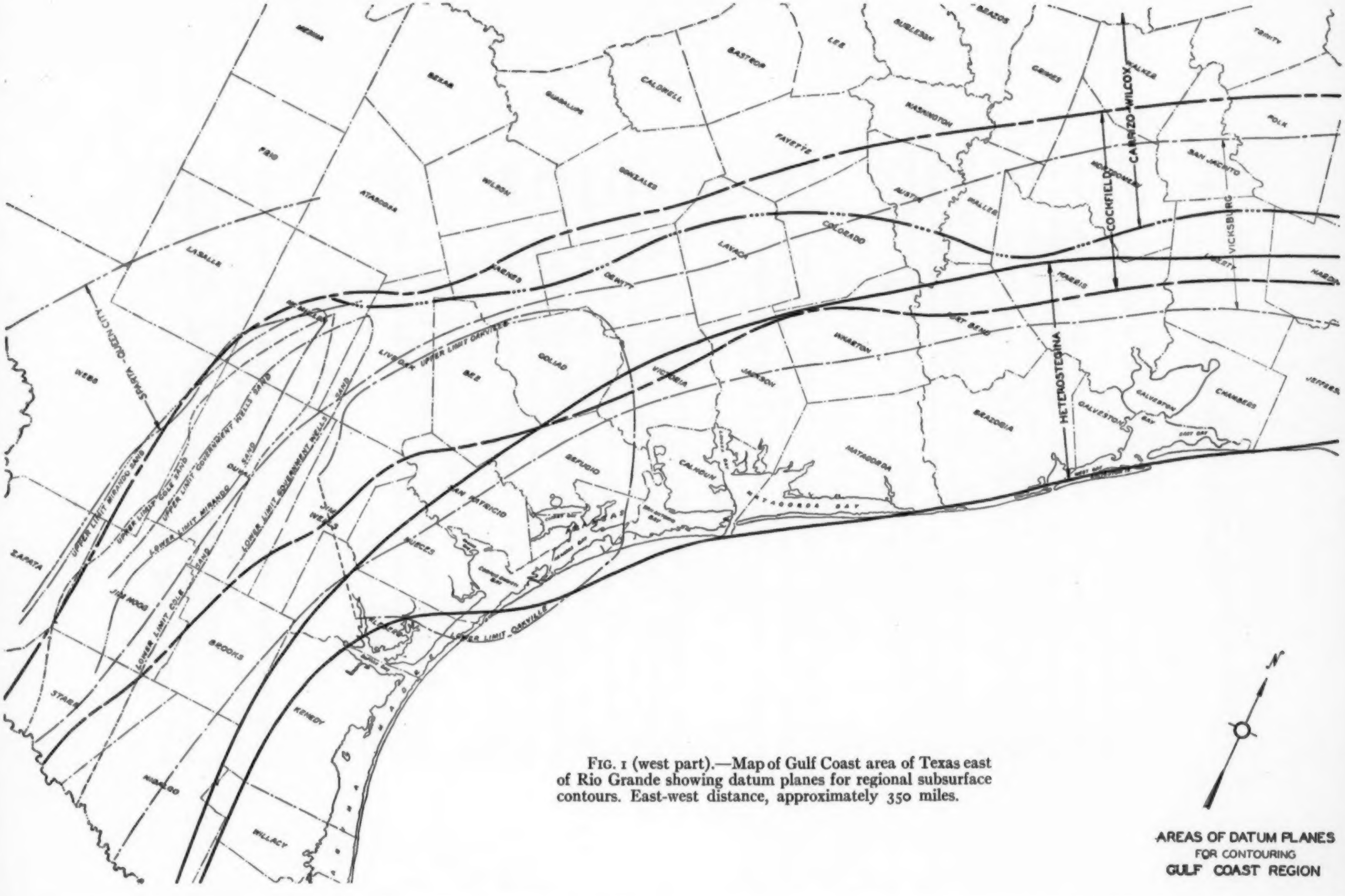

FIG. 1 (west part).—Map of Gulf Coast area of Texas east of Rio Grande showing datum planes for regional subsurface contours. East-west distance, approximately 350 miles.

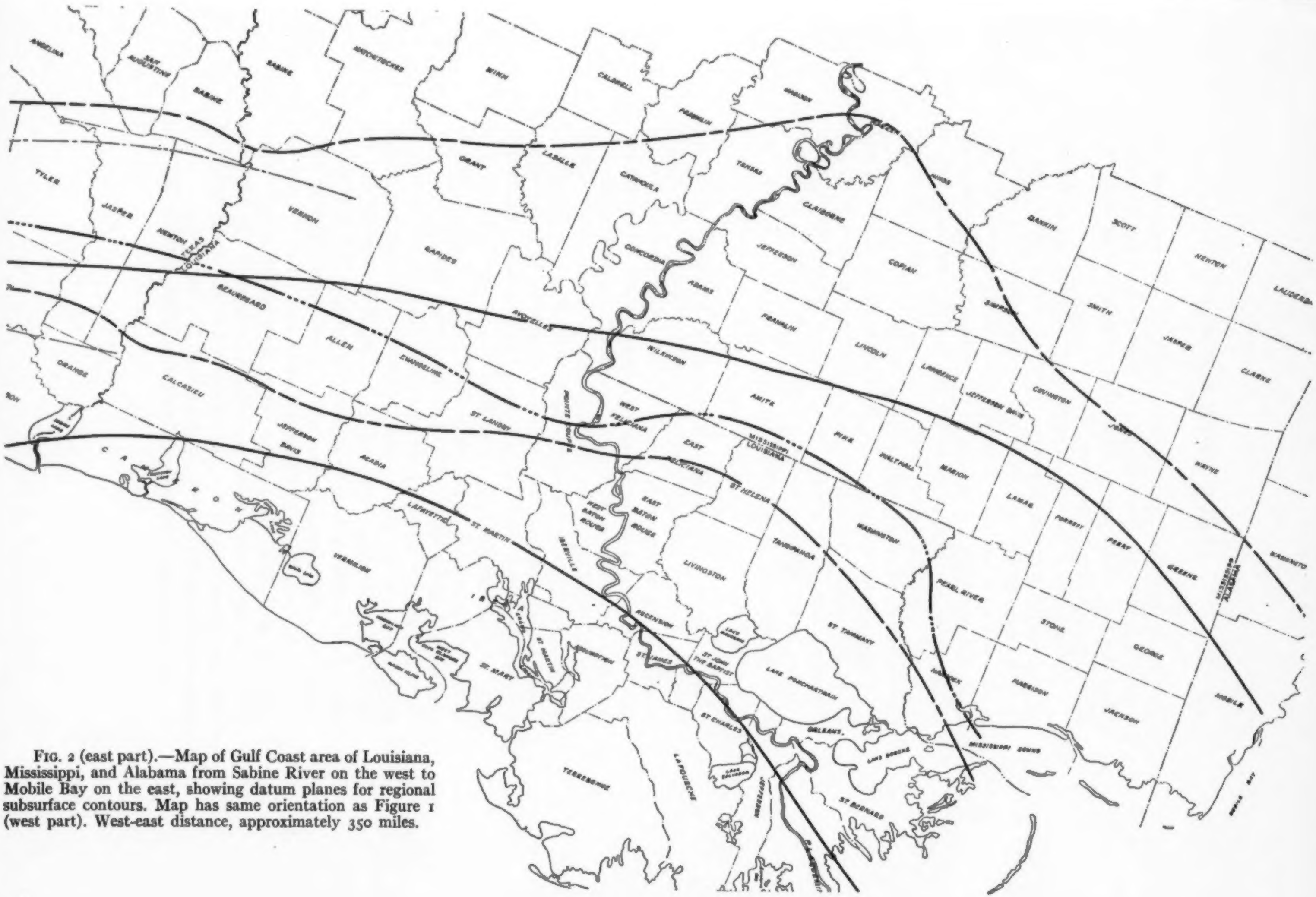

FIG. 2 (east part).—Map of Gulf Coast area of Louisiana, Mississippi, and Alabama from Sabine River on the west to Mobile Bay on the east, showing datum planes for regional subsurface contours. Map has same orientation as Figure 1 (west part). West-east distance, approximately 350 miles.

zones which they believe constitute "markers." As yet, these are distinctly individual. The reliability of these zones is not yet established but the writers are confident that at least one useful marker will be set up within the next few years.

The base of the Miocene is an excellent marker in most of the area covered by the *Heterostegina* map. It will be used in most cases to check the paleontologists' selection of the *Heterostegina* for that map. It does not seem advisable to maintain a regional map on the base of the Miocene when one is kept on the *Heterostegina* as there is not enough difference between them. For the special purpose of study of the wedge of middle Marine shales, however, a contour map on this horizon would necessarily be used with one on the "Frio."

The base of Oakville is a definite point on the electrical logs through a considerable part of southwest Texas. In most of the area, lower, and therefore better, planes are available. As this is the first definite point that can be established in drilling a well in southwest Texas, a map might be useful for early control.

OLIGOCENE

Heterostegina.—A map on this horizon is considered of first importance. The belt through which it is useful extends from Alabama to the Rio Grande and covers more than half of the production of the Gulf Coast. The top of the assemblage characterized by the genus is the basis for the datum with corrections of the paleontological selection by electrical-log correlation when near-by records are available.

The importance of this map is due to several factors. The *Heterostegina* point is still the most reliable of those selected in the middle Marine shales when one is using points given by different paleontologists. It gives structural control above the important Frio sand or its separated equivalents in Louisiana. This control in many places is available before the Frio is reached or an electrical log run.

Frio.—While it would not be a map of first importance, a map on the top of the Frio would be useful. The datum for this map would be the top of the break between the middle Marine shales and the sandy Frio section. It must be selected from electrical logs as the so-called Frio point from scout reports may be somewhat higher or lower.

This is the only datum plane selected by this group which is definitely not a time-plane. Some others may not be accurate time-planes but are as close to that as present knowledge allows. However, with the recognition of this distinction and of the exaggeration of regional dip entailed, such a map should not be confusing.

The map would be useful in giving the closest possible approxi-

mation of the depth necessary to reach the first Frio sand. In conjunction with a map on the base of the Miocene, it will outline the shape and extent of the middle Marine shale wedge, a major feature of Texas Gulf Coast stratigraphy. This map should not be extended into eastern Texas and Louisiana where sands appear in what is elsewhere the shale wedge and there is no Frio top as we have used the term. If the map were extended through by correlation, it would have no value.

Top of Vicksburg shale.—Although this is not considered a primary plane, there are considerable areas, particularly in the southwest, where the top of the Vicksburg shale furnishes the lowest reliable datum and locally the only reliable datum.

The point is selected at the top of the shales which ordinarily have *Textularia warreni* as their first reliable marker, although in places the Jackson foraminifera below are the first noted. It corresponds with the base of the sand body called "Vicksburg" by some, "basal Frio" by others. Where the Vicksburg and Jackson shales are uninterrupted by sand bodies, this point is sharp and distinctive; where the lower sand bodies appear it can usually be determined by the presence of *Textularia warreni* or by lithologic correlation so that, although less certain, it fills a definite need.

EOCENE

Hockley.—A contour map on the top of the *Textularia hockleyensis* zone has been an essential one. In recent years the data for making a Cockfield map through the same belt have been made available and the need for a Hockley map is reduced although many workers find it useful. It has the advantage of checking whether wells are structurally "high" or "low" before they reach the sand. The Hockley point is a straight paleontological selection checked by the intervals from the Vicksburg and upper Jackson faunal zones above and from the *Textularia dibollensis* zone below. The area covered by Hockley contouring coincides with that marked on the map for the Cockfield as far eastward as the Mississippi River region where the Hockley contouring ends.

SOUTHWESTERN SANDS

I. *Cole sand.*—The Cole sand, the first marked sand break above the top of the *Hockleyensis*, was formerly rather extensively used in the South Texas area, primarily because it was easily recognized from drillers' logs. Since the advent of electrical logs it has fallen into disuse as it has been learned that the Cole sand consists of a series of sand

lenses which wedge out updip with considerable abruptness, the older strand lines ordinarily lying farther inland than the younger. For this reason, unless extreme care is used in correlation, the use of this sand as a marker will afford some rather misleading subsurface information. Both the updip and downdip limits of the Cole sands finger out into shale.

II. *Government Wells sands.*—The Government Wells sands afford an excellent marker throughout the area in which they are present. This group of sands vary in thickness from slightly less than 300 feet where fully developed, to zero at its upper and lower limits. The top of the so-called lower Government Wells member furnishes the most consistent correlation point in this group; however, before selecting, careful correlations of electrical logs are necessary and, too, building of detailed cross sections is recommended for anyone not thoroughly familiar with its use as a key bed.

III. *Mirando sand zone.*—The top of the Mirando sand zone or the top of any of the lower Mirando sands, as determined from electrical logs, is an excellent key horizon within the relatively narrow belts of occurrence. The maximum thickness of the zone is approximately 350 feet, where best developed. Across the deeper part of the Rio Grande embayment it wedges out updip, but southwest and northeast of this geosyncline it extends to the surface. In its updip limits it consists of a single sand body, but seaward it breaks into as many as five distinct sands which are eventually completely replaced by marine shales.

Cockfield.—The Cockfield is a key horizon of primary importance. Typically it is selected at the sandy break just below the *Nonionella*. There are, unfortunately, considerable areas where the upper part of this section is not sandy and the selection must be the "paleo" point in shale, this point being checked by the intervals from Moody Branch fauna above and the Yegua points below. In northern Duval County the Cockfield is selected from electrical logs as the top of a thick, rather massive, series of sands occurring about 800 feet below the top of the *Hockleyensis*. In the Duval-Webb area, the limit of this lithologic break can be traced updip with fair accuracy to within approximately 2,500 feet of the surface, the downdip control being limited by depth of present exploration.

Sparta-Queen City.—Regional subsurface mapping in South Texas above the updip limits of the Mirando-Cockfield strand lines and below the practical downdip limits of Austin chalk is somewhat difficult due both to lack of suitable key beds and lack of well records. In that area, as outlined on the map for Sparta-Queen City control,

the Sparta sand can be readily selected from electrical logs. It occurs as a distinct sand body 400-500 feet below the *Ceratobulimina* and 200 feet above the Weches. The top of the thick-bedded Queen City sands occurs about 300 feet below the top of the Sparta.

Carrizo-Wilcox.—The top of the sandy formation below the lowest Mount Selman shales furnishes a datum in the northernmost belt with which Gulf Coast geologists are concerned. Generally this shows as a distinctive break on electrical logs. In South Texas, lack of data and confusion concerning Bigford sand make contouring hazardous. The Sparta-Queen City map discussed here is therefore recommended for that area.

The fact that the sandy formation underlying this datum is recognized as Carrizo in some localities and as Wilcox in others may call for later changes but, with present knowledge, it is the closest possible approximation to a uniform stratigraphic and time plane.

Lower datum planes, such as the top of the Midway or top of the chalk, are not considered within the province of Gulf Coast geology.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 23, NO. 9 (SEPTEMBER, 1939), PP. 1412-1425

REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library and available to members and associates.

MITTELAMERIKA, BY KARL SAPPER

REVIEW BY R. D. REED[1]
Los Angeles, California

Mittelamerika, by Karl Sapper (Garmisch) with the collaboration of Walther Staub (Bern). *Handbuch der regionalen Geologie*, VIII Band, 4a Abteilung. (*Central America*, by Karl Sapper, assisted by Walther Staub, *Handbook of Regional Geology*, Vol. 8, Sec. 4a.) Heidelberg, 1937, Carl Winters Universitätsbuchhandlung. 160 pp., 15 figs, 11 pls. Price, RM 27.60, less 25 per cent on orders outside Germany.

From 1888 to 1900 Professor Sapper undertook a private geological survey of Central America. Walking everywhere, counting paces, taking barometric elevations, and collecting rocks and fossils wherever he found them, he criss-crossed the land along numerous roads and trails. Most of his collections, which were scanty at best for much of the country, were lost during transport to Germany, and others shortly afterwards. He returned to Central America in 1902, 1923 and 1928, but naturally could not cover the whole country again. In addition to his own work, however, Professor Sapper has been able to learn something from his predecessors and more from his successors in Central American geology. Particularly in the last two decades, oil geologists have made intensive studies of certain areas. Other geologists have studied the routes of the Panama and (projected) Nicaragua canals. In spite of all the work done, however, the geology of Central America is still known only in a sketchy way. Probably Professor Sapper knows it better than anybody else. The volume under review tells simply and clearly what he knows and believes. Many of the data are also displayed on usable and fairly graphic black-and-white maps.

I. Morphologic Review, Earthquakes, Volcanoes

Central America is one of the two connecting links between North and South America: a western land-bridge, as contrasted with an eastern island chain. Northern Central America is genetically related to the Greater Antilles, but the largely volcanic southern Central America is not known to be so related to the likewise volcanic Lesser Antilles. The Central American land-bridge, which stretches from the Isthmus of Tehuantepec to the Atrato lowland of northwestern Colombia, is a well defined geographic unit of three-quarters of a million square kilometers. A small uplift would greatly enlarge the area of Yucatan and Panama and a sinking of 50 meters or a little more would destroy the land-bridge and restore the conditions that existed between North and South America throughout the greater part of the Tertiary. Even to-day the Nicaraguan lowland constitutes a well marked botanical boundary between the two continents and is likewise an important structural boundary.

[1] Chief geologist, The Texas Company (California). Manuscript received, June 27, 1939.

The three tectonic units of Central America are (1) the low-lying limestone plateau of Yucatan; (2) the mountainous area, with chains striking east and west, of northern Central America; and (3) the S-shaped series of mountain chains of southern Central America, with a low point at the Panama Canal where two chains meet. Both mountainous areas have peaks rising above 3,500 meters, highest of all being Tajumulco in Guatemala, 4,210 meters. The whole of Central America is about 1,900 kilometers long, the width being rarely more than 500 kilometers. Tehuantepec is just over 200 kilometers, Panama about 75 kilometers. Since the whole area lies between 7° and 22° north latitude, the lowland climate is tropical throughout, though cool north winds sometimes chill the northern plains. The *tierra caliente* is below 600 meters, *tierra templada* between 600 and 1,800 meters, and *tierra fria* above 1,800 meters. Extremely rapid chemical weathering prevails in the lowlands, particularly in the large areas of heavy forest. Thus rocks of almost any kind come to be covered with a thick mantle of very uniform soil, and rock outcrops are notably scarce. A map showing areas of rain-forest shows also many of the areas that are geologically obscure.

The divides are generally nearer the Pacific than the Atlantic shore. The relatively long Atlantic rivers often become flooded as soon as the rainy season starts and thus withdraw additional vast areas from geological observation.

The Central American volcanic belt, stretching northwest and southeast near the Pacific coast is also a belt of high seismicity. Sapper summarizes the more important data concerning both volcanoes and earthquakes, neither of which have received the attention they merit. Many of the data are shown in Figures 1 and 2. Old Tertiary eruptives are estimated to cover more than 20 per cent of the country, or about 170,000 square kilometers. Younger lavas are also spread to considerable but unknown thicknesses over vast areas.

The volcanic outbreaks of Martinique and St. Vincent in 1902 and 1903 had distinct echoes in Central America.

II. Stratigraphy and Rock Types

Crystalline schists, including gneisses, phyllites, mica-schists and serpentines[2] that look old, occur at many places in the mountains north of the San Juan River, but their age can at best only be proved to be pre-Lower or pre-Middle Permian so long as no fossils definitely older than that are known.

Paleozoic rocks are found in fairly large areas north of the Nicaraguan lowland. The oldest fossil-bearing beds, the Santa Rosa series, were once thought to be Carboniferous or in part older, but on the basis of foraminiferal studies by Professor Dunbar are now referred chiefly to Middle Permian. The strata are micaceous sandstone and shale, generally red or brown, here and there altered and crystalline. The basal beds are coarse, with fragments of mica-schist and other crystalline rocks. Toward the top the series locally becomes calcareous, or is overlain by limestones and dolomites, also Middle Permian in age according to Dunbar.

The Santa Rosa beds lie discordantly on folded beds of Carboniferous or

[2] According to Schuchert, *Historical Geology of the Antillean-Caribbean Region* (1935), p. 338, the serpentines are known to be merely post-Permian and pre-Lower Cretaceous. Thus they might prove to be of the same age as the serpentines of California.

pre-Carboniferous age and were themselves folded before the deposition of the oldest Mesozoic beds, the Todos Santos series. These are sandstone, marl, clay slate, sandy shale, and conglomerate. They are widespread and locally have yielded leaves of probable Lias age. They are coarse at the base, finer above, in many places grading upward into Lower Cretaceous limestone with fossils. Overlying them are Middle and Upper Cretaceous strata, in many places calcareous but variable in facies, and so incompletely studied as to forbid the making of any such synthesis as Burckhardt made for the Mesozoic of Mexico.

Cenozoic rocks are widespread in Yucatan and west toward the Isthmus; also in southern Nicaragua and farther southeast. Eocene foraminifera were recognized as long ago as 1889 by Schwager in samples collected by Sapper from Guatemala. Both Middle and Upper Eocene formations have been recognized since in many different places.

Beds of Oligocene age are also widely but locally distributed. Uplifts in the interior furnished coarse materials to the Oligocene seas, which nevertheless spread very widely, particularly about the margins of the Gulf of Mexico. During the Miocene the Gulf withdrew to about its present limits. Beds of this age are not certainly known in Guatemala and Honduras, but are found in many places both north and south of these countries. A strong orogenic phase seems to have closed the Miocene.

Pliocene marine strata with many fossils were recognized by Gabb at Puerto Limon in 1873, but are limited to a few small marginal areas. Nonmarine deposits of either Pliocene or Pleistocene age occur inland in many places but the exact age is generally uncertain.

Granite and other plutonic rocks of great but uncertain age occur in many places in the mountains of Guatemala and Honduras. In Çosta Rica and Panama they are restricted to the central chain. Though few analyses exist nearly all the plutonic rocks seem to be of Pacific types.

Older effusive rocks include quartz porphyry, porphyrite, and diabase. The last-mentioned type is particularly common in northeastern Nicaragua, where it carries gold-bearing pyrite. Younger effusives, as already explained, cover vast areas. Basalt and andesite are the commonest types. Tertiary volcanic activity is thought by Sonder to have embraced three phases: one probably late Eocene, a main phase in Miocene or Mio-Pliocene, and a Quaternary phase not yet extinct.

III. Geologic History

Central America consists of three structural elements: (1) a northern area with varied rocks and complex structure, analogous to the Oaxaca region of southern Mexico; (2) at the south a volcanic belt in Salvador and Nicaragua, analogous to the Mexican volcanic belt located north of the Oaxaca element; (3) the north end of the westernmost Andean chain, comprising Panama and Costa Rica.

The history of Central America is thus largely the history of the large northern element, lying more or less between two belts of active volcanoes. It is a sort of horst, constituting a separated southern element of North America and the southernmost element of Mexico. Burckhardt demonstrated that the Oaxaca area lay at the south or southwest margin of the Mesozoic Tethys that crossed Mexico from southeast to northwest. Discordant Lias and Dogger

plant beds and interbedded marine fingers in Oaxaca contrast strongly with the thick marine strata filled with ammonites in central Mexico. Tethys also crossed western Cuba but lay to the north of Guatemala, which has chiefly littoral or nonmarine Mesozoic strata. Similar conditions seem to have existed during the Permian, as a matter of fact, and also later, in the Cretaceous. The center of the Antillean Tethys always seems to have lain north of Central America, or at least of the part where Mesozoic and older strata may now be observed.

Figures 3, 4, and 5, showing the paleogeography of southern North America in Upper Jurassic, Cretaceous (Cenomanian and Turonian) and Eocene time (Middle and Upper) furnish clear pictures of the conditions inferred by Sapper and Staub. These maps should be compared carefully with those of Burckhardt, Schuchert, and Muir.

As a region marginal to Tethys, northern Central America was flooded only at the time of major transgressions—Permian, Upper Jurassic, Cretaceous. The transgressions followed long periods of denudation and their deposits carry much clastic material, particularly in the basal beds, which are reworked masses of terrestrial sediments.

The older crystalline rocks may be pre-Cambrian, as noted already, but can not be proved to be older than Paleozoic. The Paleozoic strata of Central America are preserved in a narrow, down-faulted belt north of the crystalline area of Guatemala. It was clearly much broader originally than it is now. The oldest strata carry pebbles of crystalline rock. Their deposition followed an early folding phase and may have taken place during a warm moist period, since their color is reddish. The thick limestones of the Permian are preserved only locally in Guatemala and Chiapas. Their deposition was followed by renewed folding, probably with granitic intrusion.

Jurassic conditions in Central America led to the deposition of coarse-grained strata with plant remains, much like those of Oaxaca (Todos Santos beds). In the Isthmus of Tehuantepec beds of this age lie on salt, a suggestion of an early sinking in the isthmian region. During this epoch the Caribbean is thought to have continued westward to the Pacific across southern Central America.

During the Cretaceous a seaway developed across the Oaxaca element. In Central America local and varied Lower Cretaceous deposits were succeeded by thick and widespread Middle Cretaceous (Albian to Cenomanian) limestone, much of it with rudistids. Upper Cretaceous deposits, particularly Turonian, are also widespread in both northern and southern Central America, but their exact age and detailed characteristics are not well known.

Folding phases (Laramide) at or near the end of the Cretaceous were accompanied by widespread uplift. During nearly the whole Tertiary there were straits at Panama and Nicaragua, but never at Tehuantepec.[3] Middle and Upper Eocene, generally transgressive, occur in northern Central America (or southeastern Mexico) and also in Costa Rica and Panama. A land area existed between the two. According to Lohmann volcanoes were active before the end of the period.

Oligocene time began with conglomeratic material, a suggestion of uplift in the interior districts. Ash is found in the Lower Oligocene of the Isthmus of Tehuantepec. The Gulf of Mexico was very large during the period. Oligo-

[3] On this point, however, see Schuchert, *op. cit.*, pp. 327, 378, *et cetera.*

cene beds are found in Tabasco and adjacent provinces, and also, as near-shore strata that were folded soon after deposition, in Costa Rica and Panama.

The Miocene saw a regression in eastern Mexico, but considerable areas remained submerged both in northern and southern Central America. The southern deposits are very rich in fossils. In Costa Rica Lohmann recognized two periods of Miocene folding. The one near the end of the Miocene is believed by Sapper to have been widespread and very important in bringing about present-day conditions. The salt intrusions of Tehuantepec are tentatively referred to this folding epoch.

Marine Pliocene and Pleistocene strata are found locally near the present coasts. Terrestrial deposits are numerous in the interior but their exact age is generally uncertain. The later effusives are supposed to be mostly Pliocene but may be in large part later. Tectonically, post-Miocene time has been one of gentle uplifts and faulting rather than of intensive folding.

HISTORY OF TECTONIC MOVEMENTS

The ancient core of Central America was folded once, or more probably oftener, in pre-Permian time but the exact dates are not determinable. Permian strata were folded at the close of the Paleozoic, or at any rate before the Jurassic.

The seas spread widely during Cretaceous time, but folding and regression took place at the end of the Senonian and also after Paleocene. Uppermost Eocene or Lower Oligocene folding caused uplift and a strong regression, and was accompanied by an outbreak of vulcanism. About the end of the Miocene came the orogeny that seems to have had most to do with giving the country its present structure and topography.

Sapper gives much attention to the fairly recent uplift of great "blocks" and to the development of peneplains, terraces and other physiographic features. In the absence of good topographic maps there is, as the author points out, much uncertainty about the origin and nature of most such features. In spite of the interest of the remarks about "cenotes," landslides, floods, weathering, and storms, I shall pass them by with only this reference.

IV. Orographic Elements

Under this heading, Professor Sapper discusses the geologic details of the Yucatan Peninsula; Petén and the Maya Mountains; the Isthmus of Tehuantepec; Chiapas and Tabasco; Guatemala, Salvador and West Honduras; East Honduras and Nicaragua; Costa Rica; and Panama. For most of these divisions he furnishes one of the excellent black-and-white geologic maps already mentioned. This section and the accompanying maps are thus obviously the heart of the volume, but they must be studied by those interested in them. They can hardly be abstracted usefully.

V. Important Minerals and Soils

At the time of the Conquest some Central American natives were in possession of mineral specimens that roused among the Spanish conquerors great interest and expectations that have in the main been poorly fulfilled.

In 30 years, 1904–33, Nicaragua produced $24,000,000 in gold. In 1934 all of Central America yielded 124,400 kilograms of silver. Minerals of copper,

lead, zinc, iron, manganese, and mercury all occur and some have been worked at different times and places, but none are very important at present.

Among non-metals, the small production of petroleum from the salt domes of Tehuantepec is perhaps most important of all and may easily become more important as exploration continues. Brown coal is known but not worked, asphalt is found in small quantities, sulphur occurs in some volcanoes, marble has been quarried, limestone is locally common and so, of course, is clay suitable for pottery and tiles. Rocks and structural materials are available in many places, but precious stones are practically limited to the opals of Honduras. Rock salt is known locally but not worked. Soils are the greatest mineral resource of the country and even they are commonly so thoroughly leached as to be surprisingly poor. In comparison with central and northern Mexico and with Colombia or Venezuela, Central America is in fact remarkably poor in minerals. In this respect it resembles the Antilles rather than adjoining parts of the mainland.

VI. List of Publications

The list of publications, most of which may be presumed to be also available in Schuchert's *Historical Geology of the Antillean-Caribbean Region*, runs to 6 pages, and is followed by 6 pages of additions and corrections. A table of contents and the 10 maps complete the volume. Among the latter, it remains to mention Plate I, a sketch map showing the chief structure lines of Central America, and particularly Plate II, Dr. Staub's tectonic map of Mexico and Central America, which includes the Antilles and northernmost South America.

That Professor Sapper's volume is indispensable to workers in Central American geology goes without saying. Its merits are numerous and of a kind to do great credit to the initiative and pioneering spirit of its author. Its deficiencies are merely those inevitable in any treatment of the geology of a region not yet mapped in detail either topographically or geologically. The unpretentious simplicity of the author's style and his willingness to consider alternatives even to cherished and long-published conclusions of his own are both a source of pleasure and a reason for confidence in his conclusions.

THE HIMALAYAN BORDER COMPARED WITH THE ALPS, BY ARNOLD HEIM

REVIEW BY R. D. REED[1]
Los Angeles, California

"The Himalayan Border Compared with the Alps," by Arnold Heim. *Records Geol. Survey of India*, Vol. 72, Pt. 4 (Calcutta, 1938), pp. 413–21; 3 figs.

Before the victory of the nappe theory geologists believed that the border formations of the Alps in eastern Switzerland constituted a reversed anticlinal series. The Oligocene Molasse conglomerate is commonly overlain by the Eocene Flysch with Nummulites, above which come the Cretaceous formations of the Helvetic border zone, all dipping inward toward the center of

[1] Chief geologist, The Texas Company (California). Manuscript received, June 27, 1939.

the Alps. After the nappe theory was adopted, the older idea seemed doubtful and new studies were thus in order. These soon led to the view that the Molasse is not reversed. In 1906 Arnold Heim showed that the southern border of the Molasse is not a stratigraphic horizon, that it is very irregular, and in fact was eroded into hills and hollows before being overwhelmed by Flysch masses brought by thrusting from the south. He learned also that Helvetic faults die out before reaching the Molassic foreland. Later investigations by Baumberger, Buxtorf, and others have tended to confirm these views.

An important corollary is that great Flysch lobes are found where erosion had produced hollows or lowland areas in the upraised Molasse masses. The greatest example in Switzerland is the lobe lying between the lakes of Thun and Geneva.

That similar conditions might exist in the Himalayas seemed probable to Heim, who was able to begin an investigation in 1936. The present brief paper outlines the evidence leading him to believe that the Siwaliks were also uplifted and strongly eroded before being overthrust; and that pre-Siwalik thrust-lobes occur where hollows had been previously excavated in the Siwalik upland.

KALEDONISCHE UND VARISZISCHE PROBLEME DER WESTSUDETEN, BY CHENG-SAN LEE, W. BLOCK, AND F. DAHLGRÜN

REVIEW BY R. D. REED[1]
Los Angeles, California

Geotektonische Forschungen, herausgegeben von H. Stille und Fr. Lotze, Heft 2, *Kaledonische und variszische Probleme der Westsudeten.* 106 pp. Gebrüder Borntraeger, Berlin (1938). Price, RM 6.70, less 25 per cent on orders outside Germany.

"Schichtenfolge und Bau der Oberlausitzer Schiefergebirges" (Stratigraphy and Structure of the Oberlausitz Slate Mountains), by Cheng-San Lee. 2 pls., 24 text figs.

"Das Altpaläozoikum des östlichen Bober-Katzbachgebirges" (Old Paleozoic of the Eastern Bober-Katzbach Mountains), by W. Block. 1 pl., 7 text figs.

"Bemerkungen zum kaledonischen Bau der Westsudeten" (Remarks on the Caledonian Structure of the West Sudeten), by F. Dahlgrün.

The papers by Lee and Block are detailed discussions of the northernmost part of the Bohemian mountain rampart, near where the Sudeten Mountains (Riesengebirge and several others) swing sharply southwestward into the Erzgebirge. The localities are 40–50 miles, more or less, east of Dresden. In each district Cambrian, Ordovician, and Silurian strata were strongly folded at the time of the Caledonian orogeny, Devonian strata are missing, and Carboniferous strata were folded—along with the rocks they lie on—during one of the Variscan epochs. The Sudetic orogenic phase is suggested as likely for the Oberlausitz area.

The figures accompanying these papers are good and the plates, which are colored geologic maps, are excellent.

[1] Chief geologist, The Texas Company (California). Manuscript received, June 27, 1939.

Professor Dahlgrün's brief statement is in the form of concluding remarks, designed to make clear the bearing of Lee's and Block's investigations upon the major problems of the Caledonian structure of the West Sudeten. S. von Bubnoff's *Geologie von Europa* has much excellent discussion of the same broad problem.

ZUR GERMANOTYPEN TEKTONIK, BY G. SEIDEL, W. CARLÉ, AND F. LOTZE

REVIEW BY R. D. REED[1]
Los Angeles, California

Geotektonische Forschungen, herausgegeben von H. Stille und Fr. Lotze, Heft 3, *Zur germanotypen Tektonik II.* 84 pp. Gebrüder Borntraeger, Berlin (1938). Price, RM 6.70, less 25 per cent on orders outside Germany.

"Die Dislokationszonen zwischen Bonenburg und Volkmarsen" (The Dislocation Zones between Bonenburg and Volkmarsen), by G. Seidel. 4 pls., 17 text figs.

"Die saxonische Tektonik westlich und nordwestlich des Harzes; Gittelder Graben und Lutterer Sattel" (Saxon-Type Tectonics West and Northwest of the Harz; Graben of Gittelde and Lutter Anticline), by W. Carlé. 4 pls., 26 text figs.

"Das Problem der 'Saxonischen Faltung'" (The Problem of Saxon-Type Folding), by F. Lotze. 3 text figs.

Like Heft 1, which was reviewed in the *Bulletin* for October, 1937, Heft 3 deals chiefly with the curious evidences of tension found in those parts of Germany that were folded according to the Saxon (extra-Alpine) type. These papers may thus prove to be of historical interest in a great reversal of geological opinion. It is in fact exceptionally curious that practically all present-day geologists believe—W. H. Bucher may almost be called the exception—and even a greater proportion of geologists in the period just past have believed, apparently without question, that the crust of the earth is always under greater or less compression, never except locally and accidentally under tension. That periods of widespread or worldwide tension may have existed seems to the reviewer and to Professor Bucher not only inherently likely "from the nature of things," but also strongly indicated by historical and structural evidence. Our colleagues in structural geology have been all but completely certain of the opposite. Even Professor Stille once treated the evidences of tension as exceptional but further studies in his chosen type locality, the Teutoburger Wald and its environs, have brought to light so many exceptions as to constitute a new rule. In 1936, according to Lotze, Stille formally announced dissatisfaction with his former beliefs. Lotze was already dissatisfied, it seems, and so are Seidel and Carlé. The latter's contribution, which describes a graben and a related anticline northwest of the Harz, is to the reviewer particularly interesting. All the contributions are well illustrated, though Lotze's, being primarily a discussion and conclusion, lacks colored maps but contributes some interesting original data.

[1] Chief geologist, The Texas Company (California). Manuscript received, June 27, 1939.

Lotze believes that "Saxonian folding" will prove to consist of adjustments between "blocks" at least in part. As he points out, this hypothesis necessitates a great deal of new work. And the new work, it may be, will modify the hypothesis considerably.

In any event the trend toward a belief in periods not merely of relief from strong compression but of actual widespread tension is now operating strongly. In a generation or two it is likely that one of the great puzzles of geologic history will be why present-day geologists have chosen for so long either not to see the evidence or to explain it away by so many curious devices.

GENERAL OUTLINE OF THE GEOLOGICAL HISTORY OF THE SOUTH AMERICAN CORDILLERA, BY H. GERTH

REVIEW BY R. D. REED[1]
Los Angeles, California

Boletin de Geologia y Mineria, Vol. II, Nos. 2, 3, 4 (Venezuela Geological Survey, Caracas, April–July–October, 1938). Contains papers on the geology of Venezuela and Trinidad presented before the Second Venezuelan Geological Congress, San Cristóbal, April, 1938. Printed in Spanish and English editions. 272 pp. (English edition). Many figures and maps, some in color.

Most of the papers in this bulletin are authoritative accounts of local stratigraphic, structural, and paleontologic details and problems concerning Venezuela and Trinidad. Probably all of them are important to the geologists of those countries and many are interesting and readable to those of us who live and work elsewhere. A list of the papers will be found in this *Bulletin* for June, 1939, p. 970.

One paper, Professor H. Gerth's "General Outline of the Geological History of the South American Cordillera," is of such interest and importance as to deserve extended consideration here.

During the late Paleozoic the old Brazilian Massif was bounded by mountains to southwest, west, and northwest (Gondwanids, Hercynian, or Variscan chains, more or less related in age to the old Appalachian folds of North America). The denudation of these mountains led to irregular subsidence in the area where they had stood and thus initiated the South American Cordillera. The Paleozoic and Mesozoic stages in the history of the Cordillera are discussed in Professor Gerth's fine synthesis in the series *Geologie der Erde*. The whole history of the Peruvian Andes as it was known in 1929 is well told in G. Steinmann's *Geologie von Peru*. Some of the later stages in the process are discussed interestingly in E. W. Berry's "Tertiary Flora from the Rio Pichileufu, Argentina"[2] and in Iddings and Olsson's well known study of the Peruvian oil fields.[3] Venezuelan and Colombian conditions,

[1] Chief geologist, The Texas Company (California). Manuscript received, June 27, 1939.

[2] *Geol. Soc. America Spec. Paper 12* (1938).

[3] Arthur Iddings and A. A. Olsson, "Geology of Northwest Peru," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 12, No. 1 (January, 1928), pp. 1–39.

which are complex and somewhat uncertain in several respects, are discussed in the volume under review and its predecessor, in Liddle's volume, and in other publications by such authorities as Hedberg, Kugler, and Senn.

Since Professor Gerth's complete account of post-Mesozoic rocks and events is still unavailable in the *Geologie der Erde* series, his contribution to the present bulletin, though short, is particularly welcome. The English translation is unfortunately marred by numerous typographical errors and even by a few curious-looking passages that the reviewer fails to understand. The present summary may therefore be misleading though not, it is hoped, in any essential respect.

The old Paleozoic mountains are best known in the province of Buenos Aires and in the Argentine Pre-Cordillera. Farther north small remnants are known as far as Peru, where the old range apparently divided into two. One branch struck out into the Pacific, the other continued north and east to Colombia and Venezuela, where the ancient structures are preserved only as minute fragments. As the old Paleozoic mountains were destroyed a series of "blocks" foundered, with the outpouring of chiefly acidic lavas that differ strikingly from the later Andean igneous rocks.

Into the sedimentary basin or basins thus formed the sea penetrated locally and briefly during the Trias, more definitely and broadly during Liassic and the later Mesozoic. Lower and Middle Jurassic beds are widespread but not universal in the Andes. As just now indicated, the Mesozoic Andean basin was rather a series of basins that cut obliquely from northwest to southeast across the present site of the range. The relatively small basin so well studied and described by Weaver in Neuquen, Mendoza, and farther west, is illustrative if not completely typical. Upper Liassic and Dogger strata in the central Andes are littoral toward the east, fine-grained and deep-water toward the west. Indo-Pacific faunal characters are outstanding, particularly in the Callovian. There is at present no evidence for these times and this area to prove that the sea was separated by land from the Pacific, though farther north and south a western land seems to have existed. In the Upper Jurassic, moreover, there was uplift toward the west even in the central Andes, apparently with the development of a volcanic ridge or island chain. The famous porphyrite conglomerate of Chile, which grades out eastward, has been a subject of great geological interest ever since Darwin's time. The porphyrite cobbles are characteristically Andean and Pacific.

During Oxfordian time gypsum was deposited widely in the central Andean basin. Tithonian time was marked by a renewed marine transgression that lasted into the Cretaceous. Just when the sea withdrew from the Andean basin is a difficult problem to which many answers have been given, possibly because the answer differs in different areas. Professor Weaver's Neuquen basin was destroyed by strong east-west folding during Aptian time, but the site was again flooded, this time by an Atlantic gulf, probably in the Danian (Roca stage). Professor Gerth (p. 4) refers the withdrawal of the sea from the central Andean Sedimentary Basin to a time "toward the end of the Lower Cretaceous." Steinmann dated his Peruvian orogeny and the sea withdrawal from Peru as approximately Coniacian, the evidence being that marine Coniacian fossils are widespread in the Peruvian Andes while marine fossils of later stages have not been found except adjacent to the present coast. Stille once referred the first folding and uplift of the Colombian Andes to his

sub-Hercynian orogenic phase, also approximately Coniacian. In Venezuela and Trinidad, on the other hand, the first folding of the Andes is very often stated to be Tertiary, and the Upper Cretaceous is said to be present in its entirety. This view must apparently be accepted as most probable in spite of the fact that these regions suffer from an alarming scarcity of definitely recognizable post-Coniacian Cretaceous marine fossils. Sometime during the Upper Cretaceous, in any event, the sea withdrew from the Andes, their central parts were more or less uplifted, and a vast area of red-bed deposition came into existence along their eastern margin. The beginning of this period in most areas was in the Coniacian or later, and thus definitely after the beginning of marine deposition during Albian time along the Atlantic coast. The red beds continued to be deposited, no doubt with local and temporary interruptions, until Pliocene time or later. That Tertiary deposition was interrupted by periods of strong folding in and adjacent to the Andes is certain. During one of these periods, probably Middle to Upper Miocene, vulcanism was rampant and many ore deposits were generated. Gerth states (p. 7) that the orogenic activity that initiated the first folds of eastern Colombia and Venezuela took place "during the Upper Eocene and again during the Oligocene . . . ." Upper Tertiary sedimentation was largely nonmarine and chiefly limited to intra-montane basins. The basins decreased in size as new folding movements occurred during these times. The Tertiary and later vulcanism of the Peruvian-Bolivian-Chilean area was largely absent from the northern Andes and also from Tierra del Fuego. From the evidence of an Oligocene "Patagonian sandstone" of marine character the Andes are considered to be post-Oligocene west of Patagonia. The evidence of plant and mammalian fossils as summarized by Berry, Scott, and others, suggests fairly strongly that most of the uplift and much of the deformation (marginal warping and faulting) of the entire Andean region is post-Miocene or even post-Pliocene.

Professor Gerth gives a brief statement of his conclusions concerning the relation of vulcanism to Andean uplift, and the reason he prefers for the present distribution of active volcanoes in the Andes. In general, it may be said that he assigns the folding of the central Andes directly to magmatic activity, but admits that something more like the causes ordinarily called upon for geosynclinal folding are probable for the more geosynclinal regions of "equatorial" trend near the northern and southern ends of the continent.

On one point his conclusion is definite and important.

> We can deduce from our outline of the geological history of the Cordillera that a single geosyncline, corresponding in all its length to the present Cordillera, did not exist during any period. The mountain chain that borders the continent continuously in the north, west, and south is composed of the union of fragments of very different geological history.

This conclusion, it is true, is not entirely new. Among others, Kossmat[4] insists upon it. Neither is it entirely surprising in view of what is known about oblique trends in such areas as the California Coast Ranges, Mexico, and Central America. The continuity of the Andes is, however, so great for so far as to make most interesting the search for a cause that could have produced such remarkable uniformity out of earlier diversity.

[4] F. Kossmat, *Paläogeographie und Tektonik*, p. 340 ff. Berlin (1936).

RECENT PUBLICATIONS

APPALACHIANS

*"Drainage Evolution in the Southern Appalachians," by H. D. Thompson. *Bull. Geol. Soc. America,* Vol. 50, No. 8 (New York, August 1, 1939), pp. 1323–56; 7 figs.

BRAZIL

*"Contribution to the Geology of Petroleum in the Southwest of Mato Grosso," by Glycon de Paiva and Viktor Leinz. *Divisão de Fomento de Produção Mineral Bol. 37* (Rio de Janeiro, 1939). 98 pp., 8 maps and sections, 12 photographs. In Portuguese. Six-page summary in English.

GENERAL

Petroleum Production Engineering. Oil Field Exploitation, by Lester C. Uren. 2d ed. (1939). 756 pp., 386 figs., 37 tables. Cloth. 6.5×9.25 inches outside. McGraw-Hill Book Company, Inc., New York. Price, $6.00.

*"Earthquakes and Oil Fields," by Enrique Fossa-Mancini. *Bol. Inform. Petrol.,* Vol. 16, No. 176 (Buenos Aires, Argentina, April, 1939), pp. 23–50; 11 figs.

**Hebung-Spaltung-Vulkanismus. Elemente einer geometrischen Analyse irdischer Grossformen,* by Hans Cloos. *Geol. Rundschau,* Vol. 30, Zwischenheft 4 A (1939). 527 pp., 6 pls., 60 figs. Extra issue on "Uplifting, Fracturing, Volcanism—Elements in a Geometric Analysis of Major Forms or Patterns of the Earth." Ferdinand Enke Verlag, Stuttgart, Germany. Price, 3 marks.

"A Monograph of the Foraminiferal Family Nonionidae," by J. A. Cushman. *U. S. Geol. Survey Prof. Paper 191* (1939). 100 pp., 20 pls. Supt. of Documents, Govt. Printing Office, Washington, D. C. Price, $0.30.

GREAT BRITAIN

*"Search for Petroleum in Great Britain Continues," by L. David Wosk. *Oil and Gas Jour.,* Vol. 38, No. 10 (Tulsa, July 20, 1939), pp. 19–20; 1 map.

GULF PROVINCE

"Notes on Fossils from the Eocene of the Gulf Province: I, The Annelid Genus Tubulostium, II, The Gastropod Families Cassididae, Ficidae, and Buccinidae," by Julia Gardner. *U. S. Geol. Survey Prof. Paper 193-B* (1939), pp. 17–44, Pls. 6–8, Figs. 1–6. Supt. Documents, Govt. Printing Office, Washington, D. C. Price, $0.10.

HUNGARY

*"Oil Geology of the Inner Carpathian Basin System," by Ludwig von Lóczy. *Petroleum Zeit.,* Vol. 35, No. 27 (Berlin, July 5, 1939), pp. 461–68; 5 figs. In German.

ILLINOIS

Geologic Map of Illinois. Preliminary edition subject to revision, compiled by J. M. Weller with the assistance of other members of the staff of the Illinois Geol. Survey Division (Urbana, 1939). Scale, 8 miles per inch. Blue-line print, $0.50. Order from Map Agent, State Geological Survey, Urbana.

MINNESOTA

*"St. Croixian Classification of Minnesota," by C. R. Stauffer, G. M. Schwartz, and G. A. Thiel. *Bull. Geol. Soc. America*, Vol. 50, No. 8 (New York, August 1, 1939), pp. 1227–44; 2 tables.

NEBRASKA

*"Classification of Tertiary System in Nebraska," by A. L. Lugn. *Bull. Geol. Soc. America*, Vol. 50, No. 8 (New York, August 1, 1939), pp. 1245–76; 1 pl.

OHIO AND INDIANA

*"A Petrographic Study of the Niagaran Rocks of Southwestern Ohio and Southeastern Indiana," by Richard Randall Priddy, *Jour. Geol.*, Vol. 47, No. 5 (Chicago, July–August, 1939), pp. 489–502; 3 figs.

OKLAHOMA

*"Two Lower Paleozoic Groups, Arbuckle and Wichita Mountains, Oklahoma," by C. E. Decker. *Bull. Geol. Soc. America*, Vol. 50, No. 8 (New York, August 1, 1939), pp. 1311–22; 1 table.

Oil and Gas Fields of the State of Oklahoma, prepared by G. B. Richardson, assisted by Jane Hanna. Scale, 1:500,000 (1 inch=nearly 8 miles). 34×64 inches. Director of the U. S. Geol. Survey, Washington, D. C. Price, $0.50.

PENNSYLVANIA AND OHIO

"Some Linguloid Shells from the Late Devonian and Early Carboniferous Rocks of Pennsylvania and Ohio," by G. H. Girty. *U. S. Geol. Survey Prof. Paper 193-C* (1939), pp. 47–67, Pl. 9. Supt. Documents, Govt. Printing Office, Washington, D. C. Price, $0.10.

POLAND

*"Devonian Brachiopods and Corals in the Vicinity of Pelcza in Volhynie," by Alexander V. Kelus. *Service Géol. Pologne, Inst. Géol. Pologne Bull. 8* (Warsaw, 1939). 51 pp., 3 pls., 41 text figs. In German. Polish in a special issue.

*"The Silurian of Volhynie as Shown by a Well at Dacianówka," by Zbigniew Sujkowski. *Ibid., Bull. 12.* 29 pp., 4 pls., 2 text figs. In French. Polish in a special issue.

ROCKY MOUNTAIN REGION

*"Structure of the Wasatch-Great Basin Region," by A. J. Eardley. *Bull. Geol. Soc. America*, Vol. 50, No. 8 (New York, August 1, 1939), pp. 1277–1310; 1 pl., 4 figs.

SOUTH AMERICA

Contributions to the Paleobotany of Middle and South America, by Edward W. Berry. *Johns Hopkins University Studies in Geology*, No. 13 (1939). Edward B. Mathews, editor. 168 pp., 3 figs., 23 pls. Johns Hopkins Press, Baltimore, Maryland. Price, $2.00.

TENNESSEE

"Geology and Petroleum Resources of Clay County, Tennessee," by Kendall E. Born and H. B. Burwell. *Tennessee Div. Geology Bull. 47* (1939). 200 pp., 16 pls. and figs., 6 tables. State Geologist, 124 Eighth Avenue, North, Nashville. Price, $1.00.

U.S.S.R.

Trans. Soviet Section Internatl. Assoc. Study of Quaternary (INQUA), Fascicle IV (Leningrad and Moscow, 1939). A. A. Blokhine, editor-in-chief. 160 pp., 55 articles. In Russian. Table of contents in Russian and French.

SWEDEN

*"On the Sequence of Strata in the Rhaetic-Liassic Beds of N W Scania," by Gustaf T. Troedsson. *Geol. Fören. Förhandl.*, Vol. 60, No. 3 (Stockholm, May–October, 1938), pp. 507–18; 5 figs. In English.

WYOMING

*"Pennsylvanian Formations of Central Wyoming," by C. C. Branson. *Bull. Geol. Soc. America*, Vol. 50, No. 8 (New York, August 1, 1939), pp. 1199–1226; 3 pls., 2 figs.

The Stevens Hotel, Chicago, where the twenty-fifth annual meeting of the Association will be held on April 10, 11, 12, 1940.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 23, NO. 9 (SEPTEMBER, 1939), PP. 1426–1433

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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Brooks, Benton S., Shell Oil Co., Inc., Box 218, Great Bend, Kan.
Brown, J. Albert, Kentucky Nat. Gas Co., Owensboro, Ky.
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PERMIAN SUB-COMMITTEE OF THE COMMITTEE ON GEOLOGIC NAMES AND CORRELATIONS

JOHN G. BARTRAM[1]
Tulsa, Oklahoma

At its annual meeting during the Oklahoma City convention in March, 1939, the committee on geologic names and correlations considered the many discussions of Permian nomenclature and the demands that had been made that the committee agree on and publish a standard section of the Permian for the United States. It was decided that the matter needed further study and it was voted "that the chairman appoint a sub-committee, of members of this committee, including men that know West Texas, to prepare a digest and recommendations for the classification and nomenclature of Permian

[1] Chairman, committee on geologic names and correlations.

rocks of the United States; that this sub-committee should invite the collaboration of the Association's research committee and the Permian committee of the National Research Council; and that the report of the sub-committee should be published in the *Bulletin*."

After the full committee had been appointed by the incoming president of the Association, the writer as chairman appointed to the sub-committee C. W. Tomlinson, chairman, J. E. Adams, M. G. Cheney, R. H. Dott, and R. C. Moore. The committee on geologic names and correlations consists of men who cover all areas where petroleum geologists work and who are familiar with rocks of all periods; therefore, there are not five Permian specialists on the committee, and the Permian sub-committee consists of those members who are most familiar with the problem.

The sub-committee has been at work 3 months and in addition to much correspondence has held one meeting at Fort Worth, which was attended by R. K. DeFord, editor of the proposed Permian symposium volume. They have prepared a preliminary report that has been distributed to many geologists known to be interested in the problem and to all local geologic societies. Additional copies can be obtained from C. W. Tomlinson, Simpson Building, Ardmore, Oklahoma. They have invited criticism and full discussion of the preliminary report so that it can be revised and corrected, if necessary, before final publication. They now believe that a standard section can be adopted for the Permian of West Texas and southeastern New Mexico, but they are not proposing correlations in other areas. If a standard section is adopted, then the geologists who are most familiar with the Permian of Oklahoma, Kansas, and other areas will be urged to correlate their formations with it. The suggested standard section is the one prepared and recommended by many geologists of the West Texas area.

SIXTEENTH ANNUAL MEETING, PACIFIC SECTION, LOS ANGELES NOVEMBER 9–10, 1939

The sixteenth annual meeting of the Pacific Section of the Association will be held, November 9 and 10, at the Ambassador Hotel, Los Angeles, California. At the general session on the 9th there will be an address by Association president Henry A. Ley, of San Antonio, Texas; a paper on "Soil Analysis," by E. E. Rosaire, of Houston, Texas; a paper on "Heavy Minerals"; a paper on "Present Ocean-Bottom Deposits," from the Scripps Institution of Oceanography; papers from the University of California and the University of Southern California; and a discussion of "Core Analysis." There will be a noon luncheon with a speaker. On November 10, there will be a symposium on "Recent Developments," and a symposium on "The Eocene," and the annual business meeting. A dinner dance will be held that night and everybody will go to the Stanford-University of Southern California football game the following day. Albert Gregersen, of The Texas Company, Los Angeles, is in charge of the program and E. J. Bartosh, of the Bankline Oil Company, Los Angeles, is in charge of general arrangements. Roy M. Barnes and H. D. Hobson, both of the Continental Oil Company, are president and secretary-treasurer, respectively, of the Pacific Section.

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 23, NO. 9 (SEPTEMBER, 1939), PP. 1434–1435

RESEARCH NOTES

SYMPOSIUM OF STRATIGRAPHIC TYPE OIL FIELDS

A. I. LEVORSEN[1]
Tulsa, Oklahoma

The editorial organization is complete for the special volume consisting of approximately 50 oil-field descriptions to be published by the Association through the use of the revolving publication fund. This symposium was recommended to the Association by the research committee at the Oklahoma City meeting and was there approved by the executive committee.

The fields to be described are those in which (1) sedimentary processes such as variations in porosity, permeability, and lithology, (2) lensing, (3) shore-line phenomena, and (4) various lateral gradations are dominant in the accumulation and geological environment of the oil field. Thus the emphasis is to be on fields of the stratigraphic type rather than on the predominantly structural accumulations. However, the description of each field is to be complete in that all of the elements of structure, stratigraphy, and oil-field development are to be discussed. It is hoped that this symposium of stratigraphic type fields will become a background for later philosophic studies in a manner similar to that in which our two Structure volumes[2] served as a basis for the later Problems volume.[3]

The proposed volume is to consist of essentially unpublished new material although the editorial committtee may elect to include a few of the more important stratigraphic fields which have been described in some of our earlier bulletins.

The soliciting of articles and the editorial work involved in the publication is in the hands of the following editorial board.

D. PERRY OLCOTT, Humble Oil and Refining Company, Houston, Texas
South Mid-Continent (south of Red River) and Gulf Coast
Approximately 20 oil fields to be described
N. W. BASS, U. S. Geological Survey, Tulsa, Oklahoma
North Mid-Continent (north of Red River)
Approximately 10 oil fields to be described
THERON WASSON, Pure Oil Company, Chicago, Illinois
Eastern states (east of Mississippi River)
Approximately 10 oil fields to be described
ROSS L. HEATON, Denver, Colorado
Rocky Mountain states
Approximately 5 oil fields to be described
W. S. W. KEW, Standard Oil Company, Los Angeles, California
California
Approximately 5 oil fields to be described

Anyone with ideas or suggestions as to material suitable for this symposium is cordially invited to communicate with any member of the editorial board or with the chairman of the research committee.

[1] Chairman, research committee.

[2] *Structure of Typical American Oil Fields*, Vols. 1 and 2 (Amer. Assoc. Petrol. Geol., 1929), 1290 pp.

[3] *Problems of Petroleum Geology* (Amer. Assoc. Petrol. Geol., 1934), 1073 pp.

TECTONIC MAP OF THE UNITED STATES

A. I. LEVORSEN[1]
Tulsa, Oklahoma

Following the recommendation of the research committee, the executive committee has appropriated $300.00 to be used to defray the drafting expense necessary to the preparation of a preliminary assembly of the tectonic map of the United States. Parts of this map were the subject of the evening discussion of the research committee at the Oklahoma City meeting last March.

The preparation of a tectonic map of the United States has been one of the projects of the Division of Geology and Geography of the National Research Council under the chairmanship of Chester R. Longwell. The material is now nearly complete and the preliminary assembly which this appropriation makes possible will offer a large number of interested persons the opportunity of making corrections and suggestions prior to the final engraving and printing. The drafting of the preliminary assembly is to be under the supervision of George W. Stose of the United States Geological Survey in Washington.

SURVEY OF COLLEGES ATTENDED BY MEMBERS AND ASSOCIATES OF THE ASSOCIATION

CORRECTION

The University of Illinois was inadvertently omitted in the list of "20 Highest Ranking Colleges in Number of Undergraduates," in Table III, page 1122, of the *Bulletin*, Vol. 23, No. 7 (July, 1939). Illinois should have been listed as No. 17 with 42 undergraduates who have become A.A.P.G. members or associates. Also, Illinois should have been listed as No. 19 in Table V, "20 Highest Ranking Colleges in Total Number of Undergraduates and Graduates," with a total of 76 who have joined the A.A.P.G.

[1] Chairman, research committee.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 23, NO. 9 (SEPTEMBER, 1939), PP. 1436-1438

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

A.I.M.E. Petroleum Division Meetings will be held at Galveston, Texas, October 5–7, and at Los Angeles, California, October 19–20.

IRA A. BRINKERHOFF has moved from San Antonio to become district geologist for the Stanolind Oil and Gas Company at Houston, Texas, succeeding R. A. WEINGARTNER, who is now special assignment geologist.

R. B. NEWCOMBE has changed his address to 901 North Otillia, S. E., Grand Rapids, Michigan, whence he will continue to carry on his consulting practice.

W. A. THOMAS, recently engaged in consulting work in Michigan, is division geologist for the Ohio Oil Company at Mount Pleasant, Michigan.

C. L. MOHR, geologist with the Indian Territory Illuminating Oil Company, recently stationed at Stephenville, Texas, is now at 4136 Pershing Street, Fort Worth, Texas.

FRANK A. HERALD, in charge of the Tulsa, Oklahoma, office of the Securities and Exchange Commission, oil and gas section, resigned, effective August 15. WALTER E. HOPPER has moved from Washington, D. C., to take charge of the Tulsa office.

W. A. TARR, professor of geology for many years at the University of Missouri, died at Columbia, Missouri, July 28, at the age of 58 years.

R. T. STOTLER, a recent graduate of the department of geology, Princeton University, is working for the Sinclair Prairie Oil Company at Chickasha, Oklahoma.

N. H. DARTON, accompanied by Mrs. Darton, is spending the summer in central Europe, and hopes before returning to be able to read proofs of his several contributions to the American volume of the *Geology of the Earth* now in press in Berlin. On his return to Washington in September, he will resume his investigations of the structure of part of the Atlantic Coastal Plain.

E. G. DAHLGREN, formerly in the conservation department of the Kansas Corporation Commission at Wichita, is now with the Securities and Exchange Commission, oil and gas section, at Washington, D. C.

ALFRED HARKER, emeritus reader in petrology at the University of Cambridge, died on July 29, at the age of 80 years.

GEORGE Y. MCCOY, for the past year an instructor in the department of petroleum engineering at the University of Texas, is valuation engineer with the Republic National Bank of Dallas, Texas.

CECIL B. READ, of the University of Wichita, has a discussion, "Centers of Population of Learned Groups," in *Science* of July 21, pp. 61–63. Oklahoma City, the center of population of the A.A.P.G., is the farthest west of the twelve groups shown in his tabulation. The center of the Geological Society of America is Indianapolis.

WILFRED B. TAPPER, who received the degree of M.Sc. in geology from the State University of Iowa this year, is employed by the Halliburton Oil Well Cementing Company.

F. J. SCHEMPF, of the Stanolind Oil and Gas Company, has been transferred from Tyler to Midland, Texas. He is succeeded as secretary-treasurer of the East Texas Geological Society by FRANK R. DENTON.

VICTOR OPPENHEIM has been transferred from the Anglo-Saxon Petroleum in Quito, Ecuador, to the Cia Shell de Colombia, Apartado 114, Bogotá, Colombia.

W. D. NEILER, formerly with the General Geophysical Company, is now employed by the Ohio Oil Company. His address is Box 205, Leavenworth, Kansas.

JOHN M. NISBET has returned to Bartlesville, Oklahoma, as manager of the land and geological work of the Cities Service Oil Company. His address is 705 Masonic-Empire Building.

KENNETH L. GOW, formerly district geologist for the Superior Oil Company at Mattoon, Illinois, is now in charge of the company's work at Evansville, Indiana.

LOUIS C. ROBERTS, JR., resigned, September 15, his position as division geologist for the Stanolind Oil and Gas Company at Houston, Texas, to enter independent business. He is succeeded by R. B. MITCHELL.

ROBERT I. DICKEY, geologist with the Stanolind Oil and Gas Company, has moved from Midland to San Antonio, Texas.

A. VAN WEELDEN, of N. V. De Bataafsche Petroleum Mij., 30 Carel van Bylandtlaan, The Hague, Netherlands, attended the congress of the International Union for Geodesy and Geophysics at Washington, D. C., early in September and is traveling through the United States. He will return to Europe in November.

L. M. CLARK, district geologist for the Shell Oil Company, Inc., in Kansas, has been transferred to the Illinois basin area with headquarters at Centralia, Illinois.

KENNETH KRAMMES, recently with the Superior Oil Company at Bakersfield, California, is with the Superior Oil Company of New Zealand Ltd., Suite 4, National Bank Building, Palmerston North, New Zealand.

A. L. ACKERS, of the Stanolind Oil and Gas Company, has moved from Fort Worth, Texas, to Tulsa, Oklahoma.

JAMES N. HOCKMAN, of Norman, Oklahoma, is now subsurface geologist with the Kingwood Oil Company, 327 North Third Street, Effingham, Illinois.

GUILLERMO ZULOAGA, geologist formerly with the Servicio Tecnico de Geología of the Ministerio de Fomento at Caracas, Venezuela, has joined the Standard Oil Company of Venezuela where he will be assistant chief of exploration.

MARTIN G. EGAN, of the Shell Oil Company, Inc., has been transferred from Midland to be resident geologist at Abilene, Texas.

H. DE CIZANCOURT has returned to his Paris office after several months in Venezuela, Colombia, and Antillean regions.

RALPH W. IMLAY, research associate of the geological department of the University of Michigan, has been engaged by the Arkansas Geological Survey to undertake a study of the Comanche and older formations of southern Arkansas. Imlay's work will extend through the summer and will include a study of the Comanche and older formations as they occur in Union, Columbia, Lafayette, Miller, Nevada, Hempstead, Ouachita, and Little River counties.

The West Texas Geological Society will hold its annual fall field trip this year, in conjunction with the Texas Academy of Science, meeting at the University of Texas at Austin, Texas, November 8, 9, and 10, 1939. Plans are now being made for a 2-day excursion, following the meeting, into the Llano-Burnet region. Pre-Pennsylvanian outcrops will be given especial study under the direction of well qualified guides. Details will appear in the October *Bulletin*.

CLARENCE E. MANION, formerly with the Superior Oil Company at Houston, Texas, operates the Manion Placer Mines at Blackhawk, Colorado.

CHARLES C. MASON has changed his address from the Standard Oil Company of Venezuela, Caripito, Venezuela, to the Humble Oil and Refining Company, 256 Humble Building, Houston, Texas.

W. C. IMBT, of the Stanolind Oil and Gas Company, has moved from Mattoon, Illinois, to 429 First National Bank Building, Wichita, Kansas.

ROBERT N. KOLM, of the Atlantic Refining Company, San Antonio, Texas, has succeeded IRA A. BRINKERHOFF, of the Stanolind Oil and Gas Company, as secretary-treasurer of the South Texas Geological Society since Brinkerhoff's transfer to Houston.

JOHN E. GALLEY, of the Shell Oil Company, Inc., Tulsa, has been appointed district geologist with headquarters at Wichita, Kansas.

LESLIE M. CLARK, of the Shell Oil Company, Inc., at Wichita, has been transferred to Centralia, Illinois, as district geologist.

C. L. MORGAN, geologist for the Lion Oil Refining Company, has been transferred from Shreveport, Louisiana, to Tyler, Texas.

ERNEST A. OBERING, of the Shell Oil Company, Inc., at Centralia, Illinois, has moved to Tulsa to be subsurface geologist for the company.

MRS. IRA OTHO BROWN, of San Antonio, Texas, was instantly killed in an automobile accident at Wadena, Minnesota, June 11, while on a vacation trip.

JOHN L. RICH, of the faculty of geology at the University of Cincinnati, has returned from a trip of 6 months in South America.

ELISHA A. PASCHAL has moved from Oklahoma City, Oklahoma, to Room 1202, 900 Polk Street, Amarillo, Texas, where the general offices of the Coline Oil Corporation are now located.

G. LESLIE WHIPPLE has been transferred from the Richmond Petroleum Company of Colombia, to the Indian Oil Concessions, Ltd., 2 Bath Island Road, Karachi, India.

PROFESSIONAL DIRECTORY

Space for Professional Cards Is Reserved for Members of the Association. For Rates Apply to A.A.P.G. Headquarters, Box 979, Tulsa, Oklahoma

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ROCKY MOUNTAIN ASSOCIATION OF PETROLEUM GEOLOGISTS
DENVER, COLORADO

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985 Gilbert Street, Boulder
1st Vice-President - - - David B. Miller
1336 Gaylord Street
2nd Vice-President - - - Harold N. Hickey
810 U. S. National Bank Building
Secretary-Treasurer - - - - - - Ninetta Davis
224 U. S. Customs Building

Dinner meetings, first and third Mondays of each month, 6:15 P.M., Auditorium Hotel.

ILLINOIS

ILLINOIS GEOLOGICAL SOCIETY

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Vice-President - - - - Melville W. Fuller
Carter Oil Company, Mattoon

Secretary-Treasurer - - Elmer W. Ellsworth
W. C. McBride, Inc., Centralia

Meetings will be announced.

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KANSAS GEOLOGICAL SOCIETY
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Atlantic Refining Company
Vice-President - - - - Thomas H. Allan
Consulting Geologist
Secretary-Treasurer - - - - E. Gail Carpenter
Consulting Geologist
Manager of Well Log Bureau - Harvel E. White

Regular Meetings: 7:30 P.M., Allis Hotel, first Tuesday of each month. Visitors cordially welcomed.

The Society sponsors the Kansas Well Log Bureau which is located at 412 Union National Bank Building.

LOUISIANA

THE SHREVEPORT GEOLOGICAL SOCIETY
SHREVEPORT, LOUISIANA

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Vice-President - - - - - - - - L. S. Harlowe
Grogan Oil Company
Secretary-Treasurer - - - - - - - E. F. Miller
Bay Oil Corporation, 911 Commercial Bank

Meets the first Friday of every month, 7:30 P.M., Civil Courts Room, Caddo Parish Court House. Special dinner meetings by announcement.

MICHIGAN

MICHIGAN GEOLOGICAL SOCIETY

President - - - - - - - Carl C. Addison
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Vice-President - - - - - Jed B. Maebius
Gulf Oil Corporation, Saginaw

Secretary-Treasurer - - - - R. P. Grant
Michigan Geological Survey, Lansing

Business Manager - - - - Helen Martin
Michigan Geological Survey

Meetings: Monthly dinner meetings rotating between Saginaw, Mt. Pleasant, and Lansing. Informal dress.

SOUTH LOUISIANA GEOLOGICAL SOCIETY
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Stanolind Oil and Gas Company
Secretary - - - - - - - G. O. Grigsby
Stanolind Oil and Gas Company
Treasurer - - - - - - - Baker Hoskins
Shell Oil Company, Inc.

Meetings: Luncheon 1st Wednesday at Noon (12:00) and business meeting third Tuesday of each month at 7.00 P.M. at the Majestic Hotel. Visiting geologists are welcome.

OKLAHOMA

ARDMORE GEOLOGICAL SOCIETY
ARDMORE, OKLAHOMA

President - - - - - - - - - - Don L. Hyatt
Carter Oil Company

Vice-President - - - - - - - - - J. P. Gill
Sinclair Prairie Oil Company

Secretary-Treasurer - - - W. Morris Guthrey
The Texas Company

Meetings: First Tuesday of each month, from October to May, inclusive, at 7:30 P.M., Dornick Hills Country Club.

OKLAHOMA CITY GEOLOGICAL SOCIETY
OKLAHOMA CITY, OKLAHOMA

President - - - - - - - - - Dan O. Howard
Oklahoma Corporation Commission

Vice-President - - - - Albert S. Clinkscales
Consulting Geologist, Colcord Building

Secretary-Treasurer - - - - - - R. Hancock
Magnolia Petroleum Corporation

Meetings, Ninth Floor, Commerce Exchange Building: Technical Program, second Monday, each month, 8:00 P.M.; Luncheons, every Monday, 12:15 P.M.

SHAWNEE GEOLOGICAL SOCIETY
SHAWNEE, OKLAHOMA

President - - - - - Roy P. Lehman
Phillips Petroleum Company

Vice-President - - - - - J. Lawrence Muir
Amerada Petroleum Corporation

Secretary-Treasurer - - - - Tom L. Girdler, Jr.
Sinclair Prairie Oil Company

Meets the fourth Monday of each month at 8:00 P.M., at the Aldridge Hotel. Visiting geologists welcome.

THE STRATIGRAPHIC SOCIETY OF TULSA
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The Texas Company

Vice-President - - - - - - - L. A. Johnston
Sunray Oil Company

Secretary-Treasurer - - Constance Leatherock
Tide Water Associated Oil Company

Meetings: Second and fourth Wednesdays, each month, from October to May, inclusive, at 8:00 P.M.

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Editor - - - - - - - - A. N. Murray
University of Tulsa
Associate Editor - - - - Maurice R. Teis
Homestake Companies
Meetings: First and third Mondays, each month, from October to May, inclusive, at 8:00 P.M., University of Tulsa, Tyrell Hall Auditorium. Luncheons: Every Thursday, Michaelis Cafeteria, 507 South Boulder Avenue.

TEXAS

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DALLAS, TEXAS

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Magnolia Petroleum Company

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Atlantic Refining Company

Executive Committee - - - Eugene McDermott

Meetings: Regular luncheons, first Monday of each month, 12:15 noon, Petroleum Club. Special night meetings by announcement.

EAST TEXAS GEOLOGICAL SOCIETY
TYLER, TEXAS

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Shell Oil Company, Inc.

Vice-President - - - - - - E. M. Rice
Pure Oil Company

Secretary-Treasurer - - - Frank R. Denton
Stanolind Oil and Gas Company

Meetings: Monthly and by call
Luncheons: Every Monday at 12:00 noon, Blackstone Hotel.

TEXAS

FORT WORTH GEOLOGICAL SOCIETY
FORT WORTH, TEXAS

President - - - - - - - J. Earle Brown
Consulting Geologist, Trinity Life Building

Vice-President - - - - - J. H. Markley
The Texas Company

Secretary-Treasurer - - - - Vernon Lipscomb
The Pure Oil Company

Meetings: Luncheon at noon, Worth Hotel, every Monday. Special meetings called by executive committee. Visiting geologists are welcome to all meetings.

HOUSTON GEOLOGICAL SOCIETY
HOUSTON, TEXAS

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Vice-President - - - - - - R. A. Weingartner
Stanolind Oil and Gas Company

Secretary-Treasurer - - - Carleton D. Speed, Jr.
Speed Oil Company

Regular meetings held every Thursday at noon (12 o'clock) above Kelly's Restaurant, 910 Texas Avenue. For any particulars pertaining to the meetings write of call the secretary.

NORTH TEXAS GEOLOGICAL SOCIETY
WICHITA FALLS, TEXAS

President - - - - - - - Tom F. Petty
Humble Oil & Refining Company

Vice-President - - - - Paul E. M. Purcell
701 Hamilton Building

Secretary-Treasurer - - - Orion A. Daniel
Consulting Geologist
814 Hamilton Building

Luncheons and evening programs will be announced.

SOUTH TEXAS GEOLOGICAL SOCIETY
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Sinclair Prairie Oil Company, Corpus Christi

Secretary-Treasurer - - - - Robert N. Kolm
1742 Milam Building, San Antonio

Executive Committee - - - - - E. L. Porch

Meetings: Third Friday of each month at 8 P.M. at the Petroleum Club. Luncheons every Monday noon at Petroleum Club, Alamo National Building, San Antonio, and at Plaza Hotel, Corpus Christi.

SOUTHWESTERN GEOLOGICAL SOCIETY

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Univ. Texas, Dept. of Geology

Meetings: Every third Friday at 8:00 P.M. at the University of Texas, Geology Building 14.

WEST TEXAS GEOLOGICAL SOCIETY
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Continental Oil Company

Meetings will be announced

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Meetings: Second Monday, each month, at 6:30 P.M., Kanawha Hotel.

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